DBFZ Deutsches Biomasseforschungszentrum

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GIZ/FECC 培训七"以能源生产为目的的沼气工程的运行绩效与支持政策"针对大中型沼气工程设计人员和政策决策者第四次培训 2012-5-18中国南京

How to define and provide evidence of the Performance of Biogas Plants

如何定义并提供沼气厂绩效指标




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How to define and provide evidence of the Performance of Biogas Plants
如何定义并提供沼气厂绩效指标

Efficiency: Ratio of actual power output and power input

效率：实际产出能量和输入能量的比例

What is required to evaluate a biogas plant? 需要什么来衡量沼气厂？

1. Mass balance of in- and output 进出料的物料平衡
2. Energy balance of the biogas plant, including in- and output 进出料的能量平衡
3. Data of the reliability of the equipment (hours/year) 设备的可靠性数据（小时/年）

What is needed for the mass/energy balances and the reliability data?

需要什么来获得物质/能量和可靠性数据？

1. Characterization of substrates 底物的性质
2. Analysis and evaluation of main state of the art technologies 分析和衡量主要先进技术
3. Assessment / Evaluation of the overall biogas plant concept 评价/衡量沼气厂的整体概念设计
4. Theoretical energy output as basis for the biogas plant evaluation 理论能量产出作为衡量沼气厂的基础
5. Assessment and monitoring of losses during the fermentation process of different biogas plant concepts 不同沼气厂概念设计中发酵工艺中能量损失的评价和监测
6. Possibilities for system optimization / Possibilities for increase of biogas plants performance (Repowering) 系统优化的可能性/增加沼气厂绩效的可能性

1. CHARACTERIZATION OF SUBSTRATES
底物性质

Biomass / Substrates

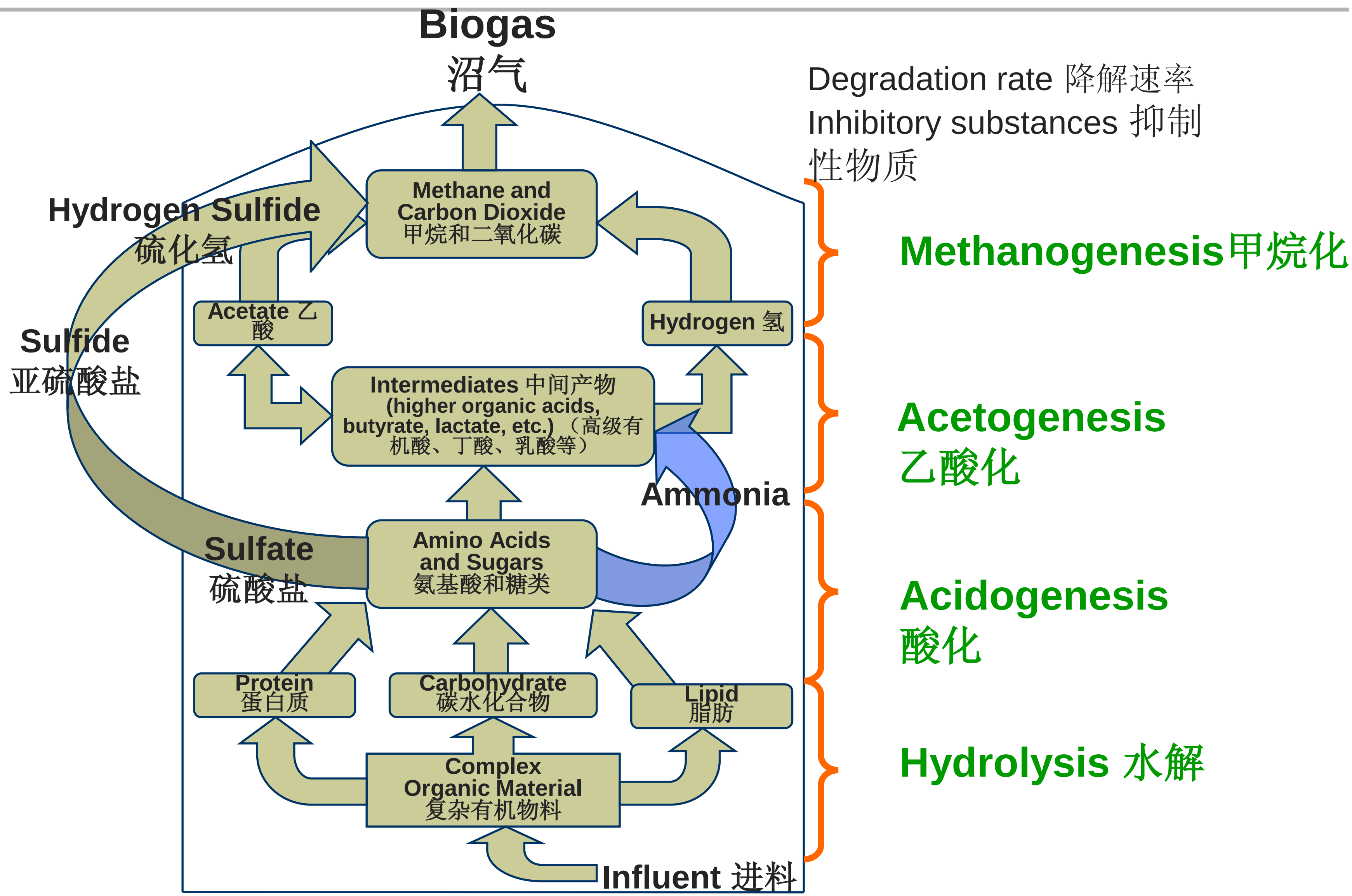
Energy crops 能源作物

By-products & Residues 副产物&残余物

Organic waste 有机废弃物

1.1. Theoretical biogas formation potential
理论产沼潜力

AD process stability and substrate characteristics
厌氧发酵工艺稳定性和底物性质



Biogas – quantification and composition
沼气 – 定量化和其组成

mixture of: methane, carbon dioxide, hydrogen, H_2S
沼气由：甲烷、二氧化碳、氢气和二氧化硫组成

$$C_nH_aO_bN_cS_d + (4n–a–2b+3c+2d)\ H_2O \rightarrow 1/8(4n+a–2b–3c–2d)\ CH_4 + 1/8(4n-a+2b+3c+2d)CO_2 + cNH_3 + dH_2S$$

1 g C = 1,868 NL biogas 沼气
1 g COD = 0,35 NL methane 甲烷

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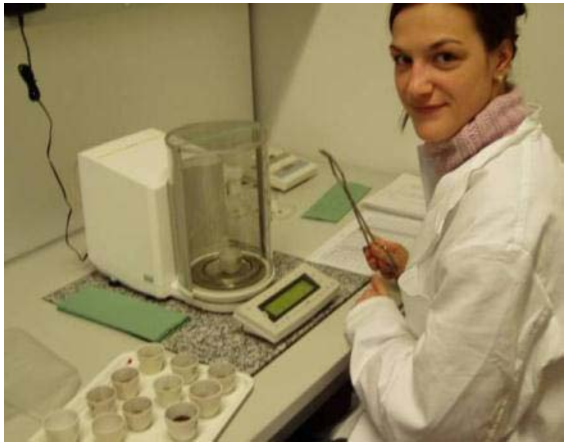
Substrate characteristics 底物性质

- Gas potential (maximum biogas yield obtainable) measured or calculated (digestion tests, animal nutrition test, elementary analysis) 产沼潜力（可达到的最大沼气产量）由测量或者计算得到（消化测试、动物营养测试、元素分析）
- Degradation rate (reduction of the concentration of organic substance) 降解率（有机物浓度的减少程度）
- Content of micro (trace) and macro elements 少量和大量元素的成分
- Content of potential inhibitory substances as nitrogen, sulphur, antibiotics etc. 潜在的抑制性物质如氮、硫、抗生素等
- Material handling: pumpability, content of disturbing material (e.g. sand, stones) 物料处理：泵送能力，干扰物质含量（如砂、石头）

Characterization of Substrates - Composition 底物性质 – 组成

- Dry matter content (DM): waterless (anhydrous) share of a mixture after drying at 105 °C. 干物质含量（干物质）：底物混合物在105 °C下干燥后无水部分的比例
- Organic dry matter content (oDM): Mixture free of water (anhydrous) and free of inorganic substances generally per drying at 105 °C and annealing at 550 °C 有机干物质含量（oDM）：底物混合物经过105 °C下干燥和550 °C 下热解计算得到的不含水和有机物的比例
- Fractions of fat, protein and carbohydrate analyzed by “Weender” – Animal nutrition analysis 脂肪、蛋白质和碳水化合物成分 - “Weender”动物营养分析

Representative samples of the biomass are essential for meaningful results!
获取有代表性的生物质样品是获得有意义结果的关键！

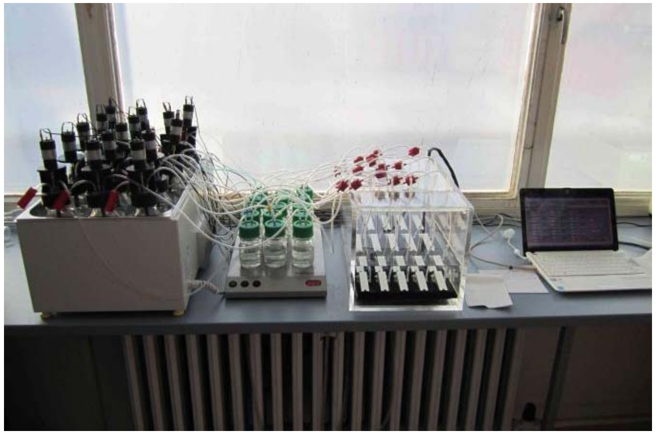


Methods of substrate´s characterization

Animal nutrition analysis
动物营养分析

Continuous anaerobic digestion
连续厌氧发酵反应器

Discontinuous anaerobic digestion非连续式厌氧发酵

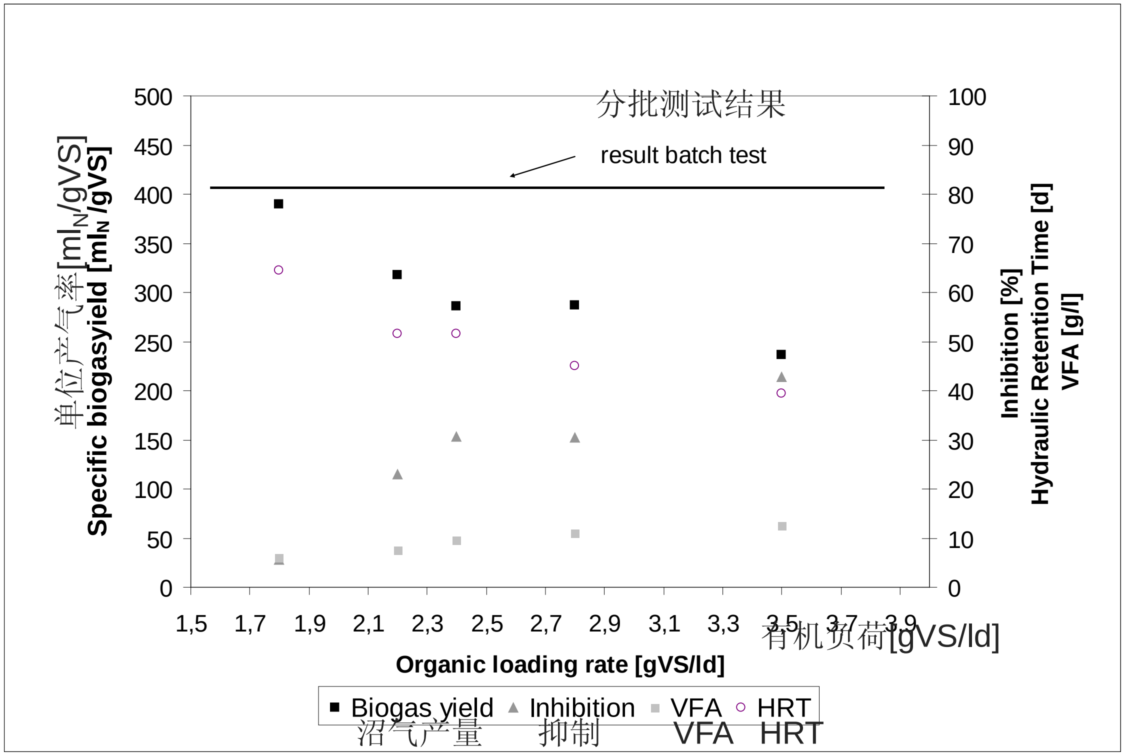


Methods of substrate´s characterization 确定底物性质的方法

	Effort 投入	Informative value 信息价值
Digestion tests 消化测试		
Batch 分批试验	Medium (approx. 35 days) 中等（约35天）	Medium (general degradability) 中等（一般可降解性）
Continuous 连续实验	High (months) 高（数月）	High (degradability under real conditions, inhibition, deficiencies) 高（实际条件下的可降解性、抑制因素和不足因素）
Tests to calculate the biogas yield 计算沼气产量的测试		
Animal nutrition 动物营养	Medium (approx. 1 week) 中等（约一周）	Medium (fat, protein, various carbohydrates, ash) 中等（脂肪、蛋白质、各种碳水化合物、灰分）
Elementary analysis 元素分析	Medium (approx. 1 week) 中等（约一周）	Low (all elements, but carbon as lignin is not degradable) 低（所有元素，但是以木质素形式存在的碳不可降解）
Data from literature 文献数据	Low 低	Depended on the quality of source 取决于数据来源质量

Representative samples of the biomass are essential for meaningful results!
获取有代表性的生物质样品是获得有意义结果的关键！

Batch vs. continuous tests
分批 vs. 连续测试



抑制作用[%]
水利停留时间 [d]
VFA[g/l]

Results of the continuous tests 连续测试的结果

Table 1: Results of the continuous tests

表1：连续测试结果
有机负荷[goTS/ld]
单位产气率[mlN/gVS]
产气降低[%]

Organic loading rate [goTS/ld]	1.80	2.20	2.40	2.80	3.50
Specific gasyield [mlN/gVS]	389.83	318.00	285.80	286.82	236.01
Yield reduction [%]	5.53	22.94	30.74	30.49	42.80
VFA [g/l]	5.89	7.46	9.61	10.95	12.60
HRT [d]	64.41	51.55	51.55	45.06	39.46
NH_4^+-N_T [mg/l]	5,14	5,18	5,27	5,72	5,53
NH_3-N [mg/l]	709,5	683,9	611,1	720,7	628,1

Biogas 沼气

- Energy content: 4-7 kWh/m³, depended on methane content (methane: 10 kWh/m³) 能量含量4-7 kWh/m³，取决于甲烷含量（甲烷10 kWh/m³ ）
- Equivalent to oil: app. 0,62 l/m³ gas 原油当量： 约0,62 l/m³ 沼气
- Useable amount for electricity : 1,8-2 kWh_{el}/m^3 Biogas 转化为电力1,8-2 kWh_{el}/m^3
- Approx. 2/3 of energy is heat 约 2/3的能量转化为热
- Explosion range: 4-16 Vol. % in air 爆炸极限：空气中体积比4-16%
- Density: 1.2 kg/m³ 密度: 1.2 kg/m³
- Ignition temperature at 700 ºC 着火点： 700 ºC

Annual demand of a German household

德国家庭的年能耗:	3,500 kWh
equivalent to等同于:	2,000 m³ Biogas 沼气
equivalent to等同于:	20 t Biowaste (ca. 100 kg/inhabitant/a) 生物垃圾（约100kg/人/年）
equivalent to等同于:	80 t pig manure 猪粪

1.2. Biodegradation kinetics
生物降解动力学

Continuous stirred tank reactor (CSTR) 连续搅拌反应罐

Conversion to methane simplified to one process

产沼简化为单一过程

$Continuous$:连续式反应

$$\frac{dS}{dt}V = QS_0 - QS_t + V\ r_s \qquad (7)$$

$$r_s = -\frac{\mu_{max}}{Y}\frac{S}{k_S + S}X \qquad (8)$$

$Assumption\ continuous$:假设为连续

$$\frac{dS}{dt} = 0(steady\ state);\ k_S >> S_0;\ X >> S_0;\frac{\mu_{max}}{Y\ k_S} = k; D = \frac{1}{\theta}$$

$$0 = Q\ (S_0 - S_t)\ -\ k\ S_t \qquad (9)$$

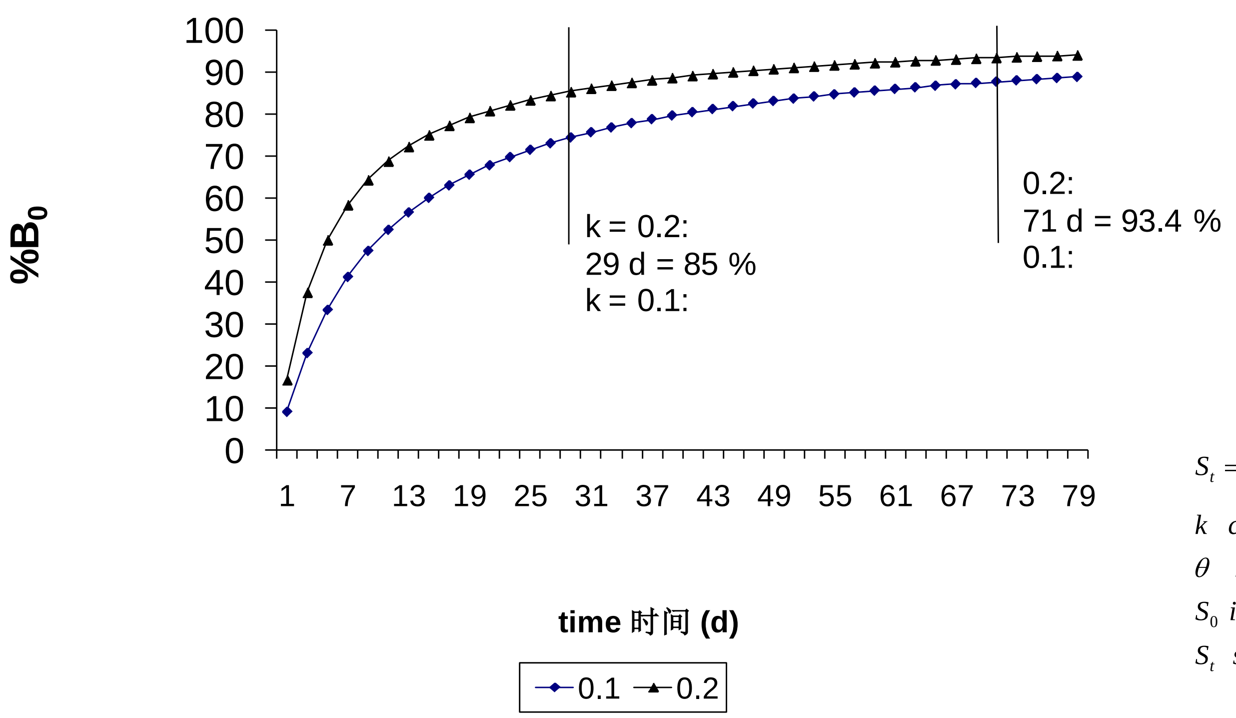
$$S_t = \frac{S_0}{1 + \frac{k}{D}} = \frac{S_0}{1 + k\ \theta} \qquad (10)$$

X	$Bacteria\ concentration$ 细菌浓度
S	$Substrate\ concentration$ 底物浓度
S_0	$Initial\ substrate\ concentration$ 初始底物浓度
S_t	$substrate\ concentration\ at\ time\ t$ 时刻t的底物浓度
μ_{max}	$maximum\ growth\ rate$ 最大生长速率
μ	$growth\ rate$ 生长速率
Y	$yield\ (g\ bacteria\ mass\ per\ g\ substrate)$ 产气量（g细菌每g底物）
V	$volume$ 容积
r_s	$reaction\ rate$ 反应速率
D	$flow\ rate\ (throughput\ Q/V)$ 流速(通量 Q/V)
Q	$flow\ rate\ (V/time)$ 流速(V/时间)
θ	$retention\ time$ 停留时间
t	$time$ 时间
k_S	$Monod\ constant,\ concentration\ at\ which\ \mu = \frac{1}{2}\mu_{max}$ 莫诺德常数，$\mu = \frac{1}{2}\mu_{max}$时的浓度

Retention time and yield in a first order scenario
一阶反应的停留时间和产气量

The kinetic depends on the type of biomass and the kind of pre-treatment
反应动力学取决于生物质的种类和预处理方式

% gas produced 沼气产量%
CSTR in a first order scenario
CSTR一阶反应情况



$$S_t = \frac{S_o}{1 + k \times \theta}$$

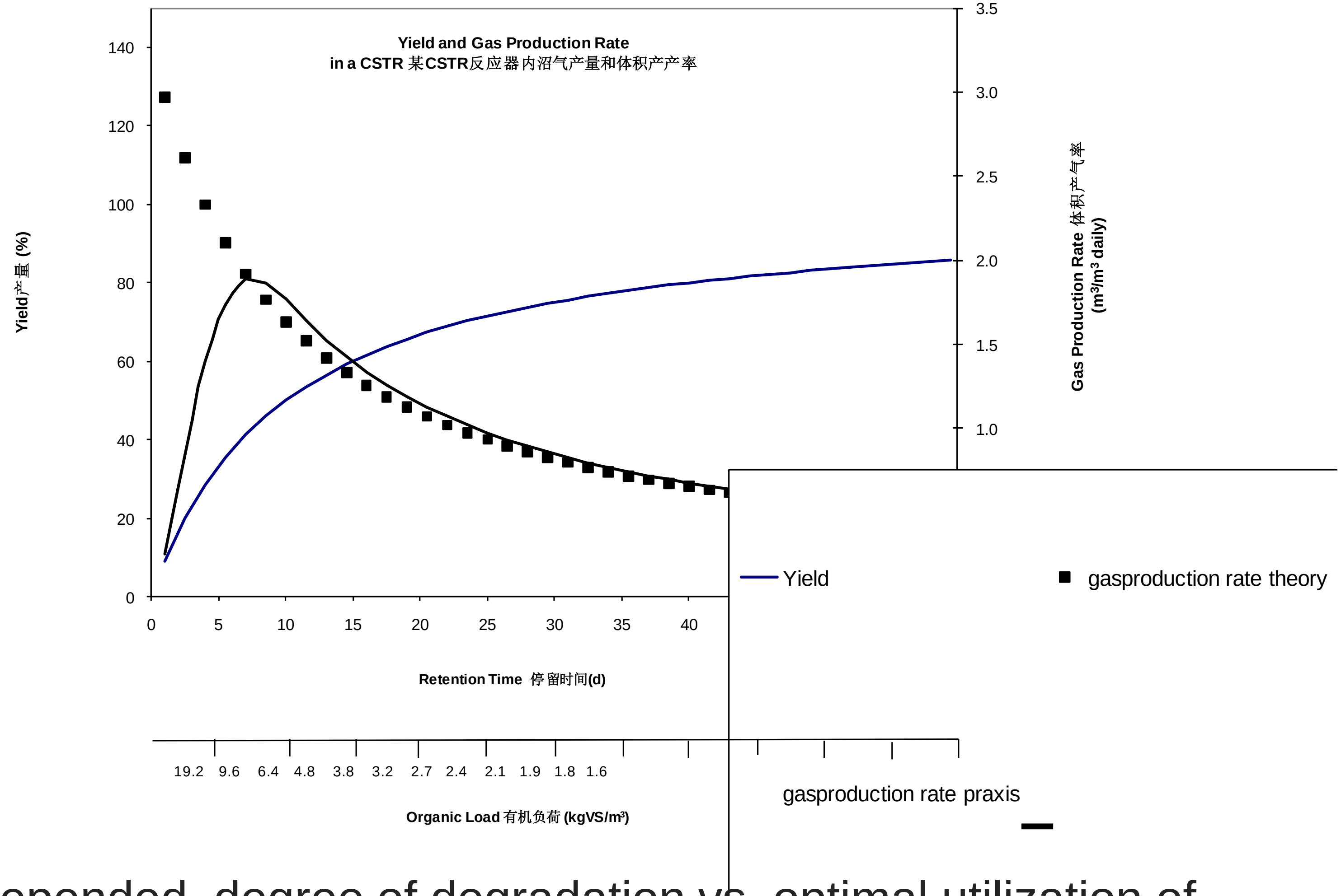
k *conversion rate* 转换率

θ *retention time* 停留时间

S_0 *initial substrate concentration* 初始底物浓度

S_t *substrate concentration at time t* 时刻t的底物浓度

Yield and reactor utilization 产气量和反应器利用率



Substrate depended, degree of degradation vs. optimal utilization of digesters volume, crucial for plant design and economics 取决于底物，降解率 vs 反应器容积更佳利用率。对沼气厂设计和经济性极为关键

Characterization of Substrates - Gas yield and Quality

Substance 底物	Biogas yield 沼气产量	Methane concentration 甲烷浓度	Heating value 热值
	[l/kg oDM]	[Vol.-%]	[kWh/m³]
Carbohydrates 碳水化合物	700 - 830	50 - 55	5,0 - 5,5
Proteins 蛋白质	700 - 900	50 - 55	5,0 - 5,5
Fats 脂肪	1.000 - 1.400	68 - 73	6,8 - 7,3
Biowaste 生物垃圾	350 - 500	55 - 68	5,5 - 6,8
Energy crops 能源作物	500 - 700	50 - 62	5,0 - 6,2

Chart changed,after: Weiland, P.: Biologie der Biogaserzeugung; Institut für Technologie und Biosystemtechnik der Bundesforschungsanstalt für Landwirtschaft (FAL); ZNR Biogastagung, Bad Sassendorf-Ostinghausen, 02.04. 2003

Biogas potential 产沼潜力

Substrate 底物	TS, VS %, %TS	biogas potential 产沼潜力 m^3/t substrate底物	biogas potential 产沼潜力 m^3/t VS
cow manure 牛粪	8-11, 75-82	20-30	200-500
pig manure 猪粪	7, 75-86	20-35	300-700
cow manure 牛粪	25, 68-76	40-50	210-300
Chicken manure 鸡粪	32, 63-80	70-90	250-450
Corn silage 玉米青贮	20-35, 85-95	170-200	450-700
Rye silage 麦青贮	30-35, 92-98	170-220	550-680
Molasses 废糖蜜	80-90, 85-90	290-340	360-490
Separately collected biowaste 专门收集的生物垃圾	40-75,50-70	80-120	150-600
Lipids from grease separator 隔油池分离出来的脂肪	2-70, 75-93	11-450	700
Glycerin (SEEG) 甘油	47, 70	425	1295

Untersuchungen zur Wirkung von Rohglycerin aus der Biodieselerzeugung als leistungssteigerndes Zusatzmittel zur Biogaserzeugung aus Silomais, Körnermais, Rapspresskuchen und Schweinegülle

Ergebnisbericht, Mai 2004

Im Auftrag von
Südsteirische Energie- und Eiweißerzeugung Reg.Gen.m.b.H. (SEEG)
Pestkreuzweg 3
A-8480 Mureck

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Characterization of Substrates - Conclusion 底物特性 – 结论

- Substrates differ in energy density, composition and degradability 底物的能量密度、组成和可降解性各不相同
- Mostly pre-treatment enhances the degradability of substrates, except for lignin, which is only aerobic degradable 多数情况下预处理能增强底物的可降解性，而木质素除外，只能好氧降解
- High amounts of extreme easy degradable substrates can lead to process failure, due to a excessive acid production 大量极易降解底物容易导致系统崩溃，原因在于产酸过量
- Mono-fermentation can lead to an unbalanced nutrient supply, therefore a suitable mixture of substrates or a supply with lacking nutrients are recommendable 单一物质发酵可能导致营养供给不平衡，因此建议混合合适的底物或者提供其缺乏的营养物
- High concentrations of ammonia can lead to difficulties in the biological process 高浓度的氨能导致生物反应困难
- High concentrations of sulphur can cause damage e.g. CHP 高浓度的硫会损害CHP
- Sand and stones can lead to technical difficulties 砂石会带来技术难题

2. ANALYSIS AND EVALUATION OF MAIN STATE OF THE ART TECHNOLOGIES
分析和衡量主要先进技术

General technical requirements
一般技术要求

- high reliability/durability and short maintenance interruptions of all plant components are essential for high operating and full load hours – the overall process has to be reliable! 全厂所有部件都具有高可靠性/耐久性，维护影响小的特点，是高运行荷载和时间的关键 – 整个工艺必须可靠
- Technology has to match the substrate/biomass, sufficient flexibility for change in substrate 技术必须适应底物/生物质，为底物变化保留灵活性
- Capacity of the plant as a whole and the plant components have to match the actual substrate and mass flows 沼气厂的能力是一个整体，各个部件必须满足实际底物和物质流量
- Low energy consumption 低能耗
- Easy to monitor and control 易于监测和控制

2.1. Digester types 反应器类型

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Biomass and reactor type
生物质和反应器类型

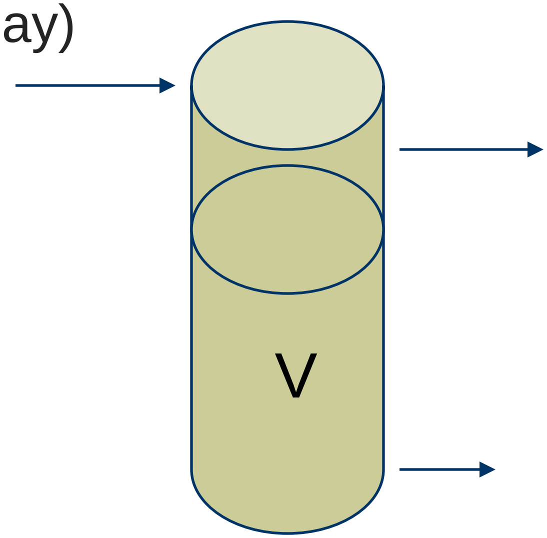
- Digester type is selected according to the substrate characteristics 根据底物性质选择反应器类型
- UASB, fixed bed digesters for substrates with low TS concentrations TS浓度低的底物采用UASB，固定床反应器
- Agricultural application TS between 3 – 12 % continuous stirred tank reactor (CSTR), manure and Energy crops 农业的粪便和能源作物其TS为3-12%，采用CSTR反应器
- plug flow digesters mostly for higher total solid concentrations 推流式反应器通常用于更高TS浓度底物
- Box/garage type digestion only for biomass, which is stackable and can be easily saturated by percolate (landscape management material, seperatly collected biowaste), highly insensitive to sand, rocks, disturbing material 箱式/车库式反应器只用于可以堆积且易于饱和渗滤的生物质（园林垃圾和单独收集的有机垃圾），对砂子、石块和其他干扰物质非常敏感

Continuously driven reactors
连续进料反应器

substrate infeed 底物进料

Q x S_o

(kg/day)



Biogas 沼气

Digestate 沼渣沼液

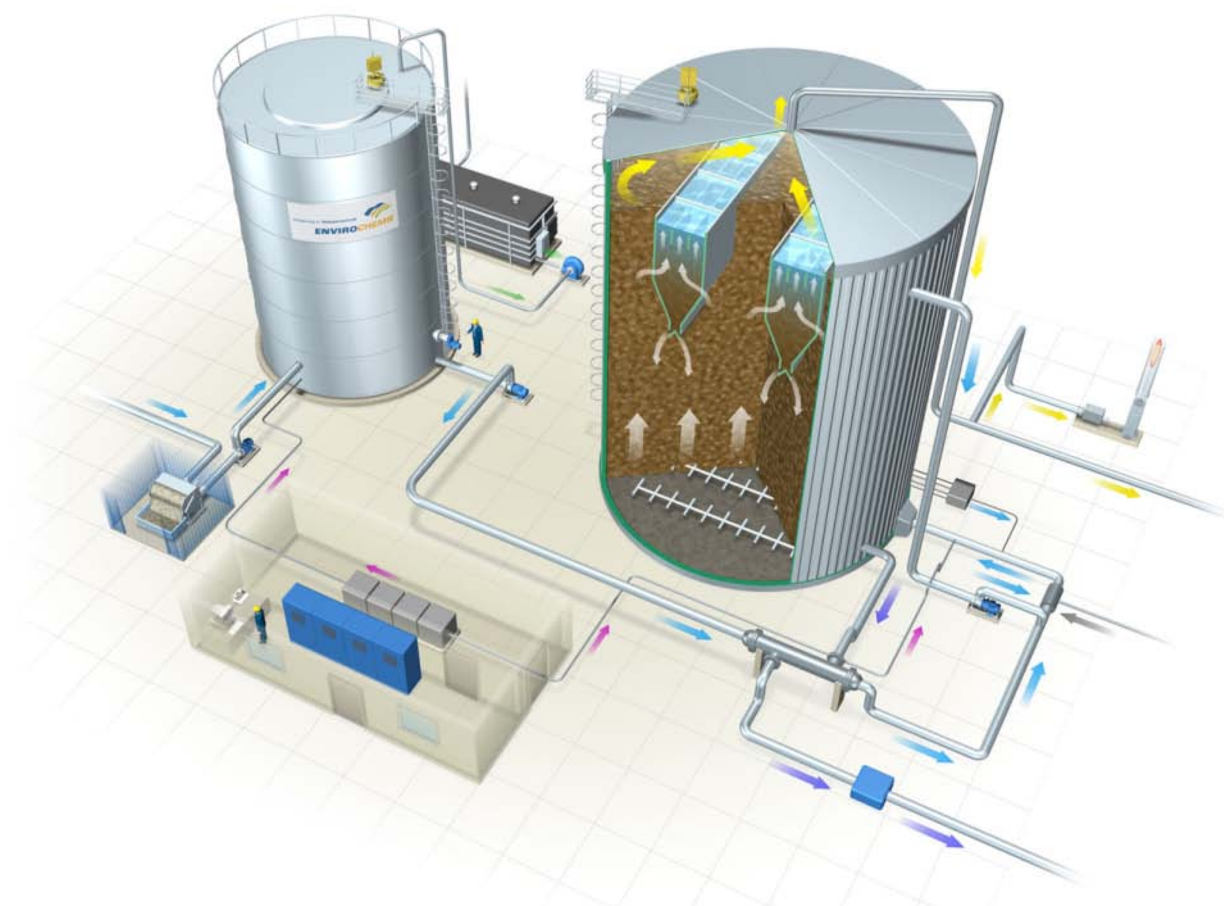
Q x S

(kg/day)

Optimum 最好是:

steady state, means substrate and bacteria concentration constant 稳定状态，意味着底物和细菌浓度保持恒定

Anaerobic sludge bed reactor
厌氧污泥床反应器

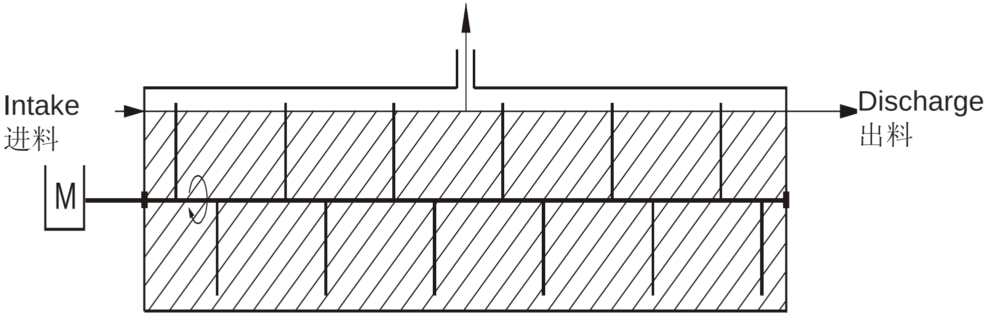


Picture: EnviroChemie (http://www.envirochemie.com/envirochemie/de_DE/index.php)

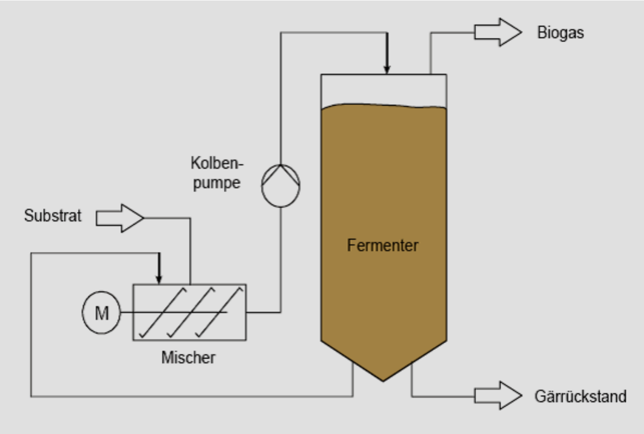
Continuously stirred tank reactor (CSTR)
连续搅拌反应器（CSTR）

Plug Flow Tank Reactor (PFTR)
推流式反应器(PFTR)

Horizontal
水平式



Vertical
垂直式



Continuously driven Reactors - Further Digester Types
连续进料反应器 – 更多反应器类型

Ring-In-Ring-Digester 套环式反应器
(space saving construction) 节约空间

Pfefferkorn - Digester Pfefferkorn 反应器
(energy saving mixing) 节约混合所需能量

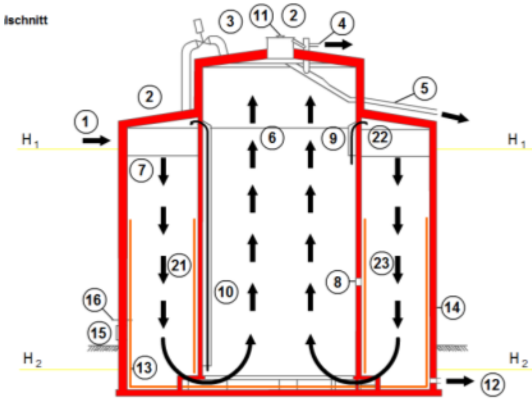


Foto: Agronet VSP

Rectangular Digester 方形发酵罐
(plug flow) 推流式

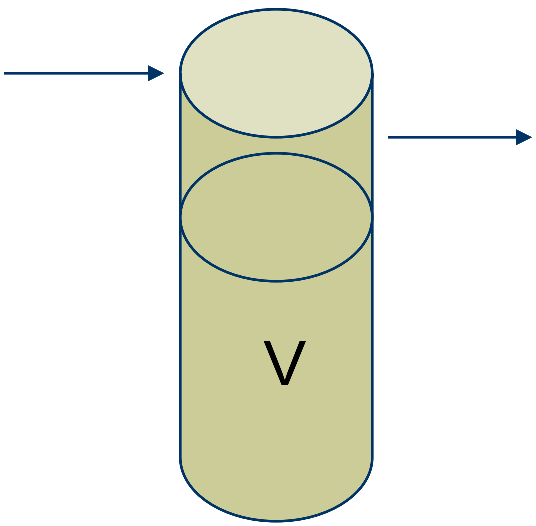
Foto: DBFZ

Lagoon Digester 厌氧塘
(energy saving mixing)节约混合所需能量

Foto: DBFZ

Batch Reactor 序批式反应器

substrate infeed +
inoculum 底物+接种细菌
(kg)



Biogas 沼气

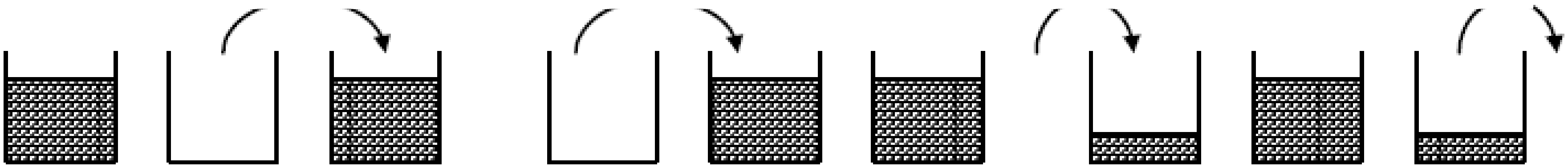
Digester is fed and left for a certain period of time, then emptied 发酵罐进料后停留一段时间，然后清空

Batch Reactor 序批式反应器

Phase 1: Clearance
阶段1：清空

Phase 2: Filling
阶段2：进料

Phase 3: Digestion
阶段3：发酵



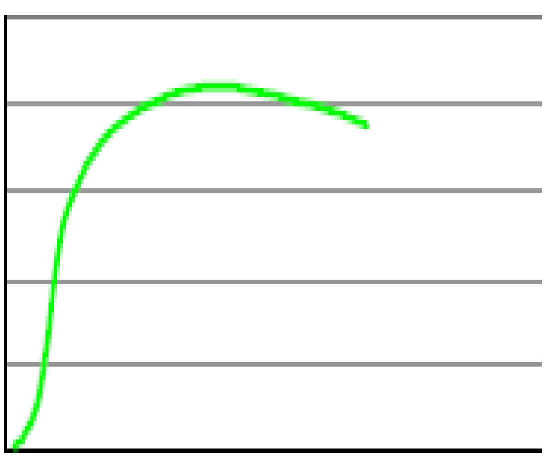
storage tank full 储存罐满 | digester empty 发酵罐空 | storage tank full 储存罐满

storage tank empty 储存罐空 | digester full 发酵罐满 | storage tank full 储存罐满

储存罐空 | digester full 发酵罐满 | 储存罐空

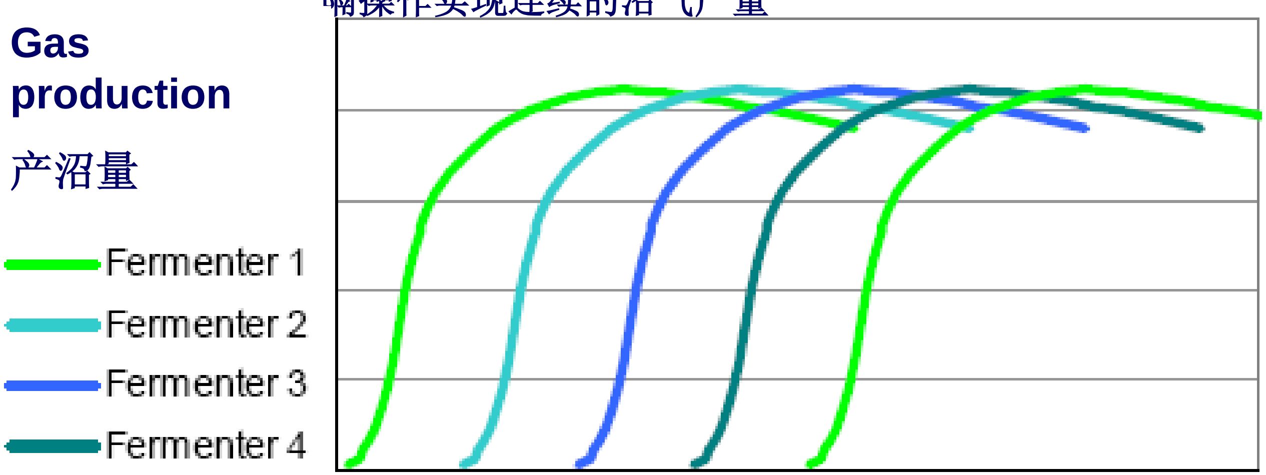
Gas production in a discontinuous solid phase digestion 非连续固相发酵期间的产沼量

Continuous gas production through time shift operation of several digesters 通过几个发酵罐时间间隔操作实现连续的沼气产量



Gas production

产沼量

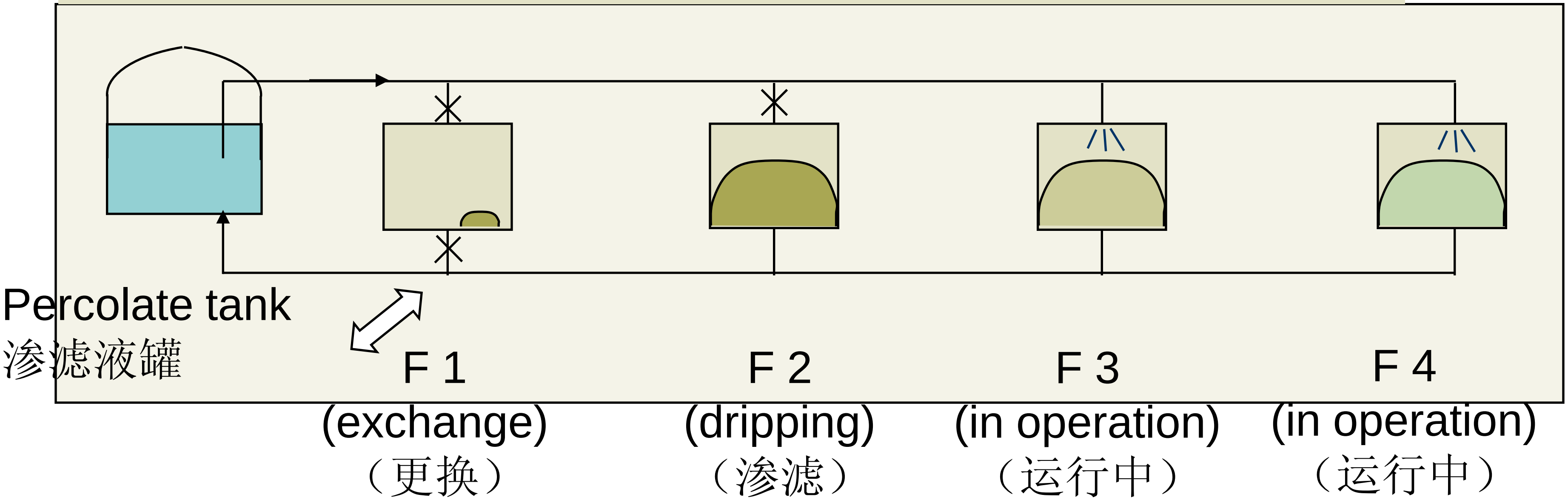


Retention time 停留时间

Retention time停留时间

Batch Reactor 序批式反应器

System: Multiple garage/box type digesters with percolate tank
系统：多个车库/箱式反应器和渗滤液罐

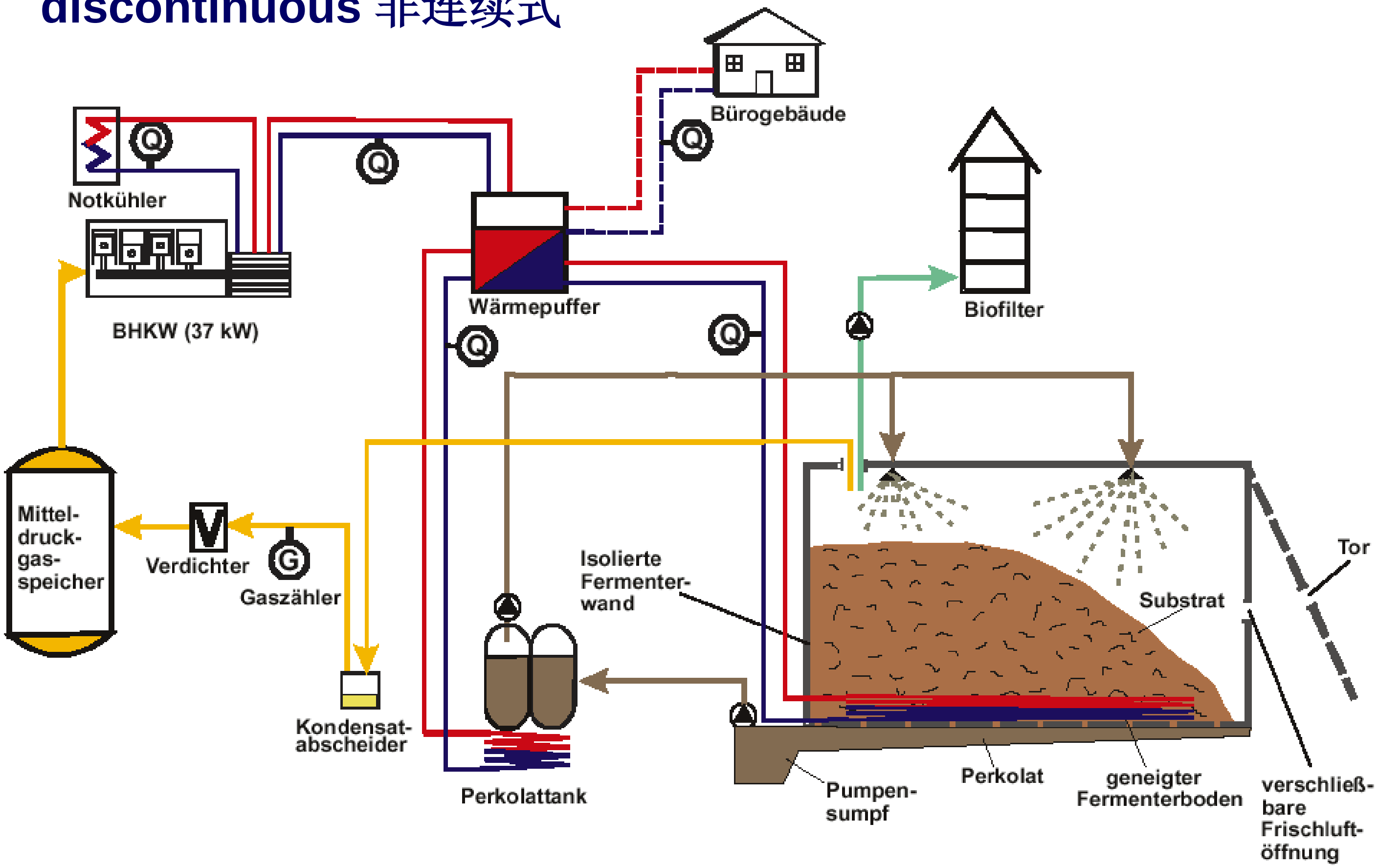


Trend: The amount of percolate had to be increased for serveral systems.
趋势：渗滤液的量在几次循环后必须增加

Batch Reactor序批式反应器

Garage type digester 车库式反应器

discontinuous 非连续式



Prozeßschema Boxenfermenter (Abbildung: BEKON GmbH Co. KG); Fotos: Bekon GmbH (oben), DBFZ (unten)

2.2. Pre-treatment 预处理

Pre-treatment of organic matter – Aims and Challenges 有机物的预处理 – 目的和挑战

- Increasing biogas yield by cell disruption and enlargement of surface (lignin und cellulose containing substrates) 通过破坏细胞膜和增加表面积（含木质素和纤维素底物）增加沼气产量
- Acceleration of degradation and therewith a more efficient use of the biogas plant (all substrates in common) 加速降解速率，从而更有效的利用沼气厂（所有底物的共同点）
- Avoiding of layers of floating or/and sinking matters and therewith the decreasing of energy effort for mixing and pumping 避免浮渣层或/和沉积层从而降低搅拌和泵送的能耗
- Securing of the digestion process by improvement of the input material´s quality (e.g. sugar beets or bio waste) 提高原料质量，保护厌氧消化过程（如甜菜或者生物垃圾）
- Cost and energy efficiency 费用和能效

Pre-treatment of organic matter - Disintegration – methods
有机物预处理 – 分解 – 方法

- **Physical methods** (numerously available, but scope of application should be considered) 物理方法（方法非常多，但需考虑适用范围）
  - Disintegration by crushing or milling 破碎或碾磨分解
  - thermal treatment by hot water, steam or hydrolysis with heat and pressure (combination of different methods) 用热水、蒸汽或者加热加压水解进行热处理（不同方法结合）
  - Radiation by microwave or ultra sound 微波辐射或者超声波
- **Chemical methods 化学方法**
  - use of acids or bases (at present not relevant in practice, due the high demand of acids/bases and the impact of the methanogenesis) 用酸或者碱（目前由于酸碱消耗量过大及对甲烷化过程的影响没有实际应用）
- **Biological methods** (microorganisms and enzymes) 生物法(微生物和酶)
  - as an additive for ensilage to minimize losses 作为青贮添加剂以减少损失
  - hydrolytic bacteria for disintegration of substrates containing lignocellulose 加入水解细菌分解含木质纤维素底物

Pre-treatment of organic matter - Disintegration – methods
有机物预处理 – 分解 – 方法

Macerator with contraries removal

带杂质去除的切割机

Extruder

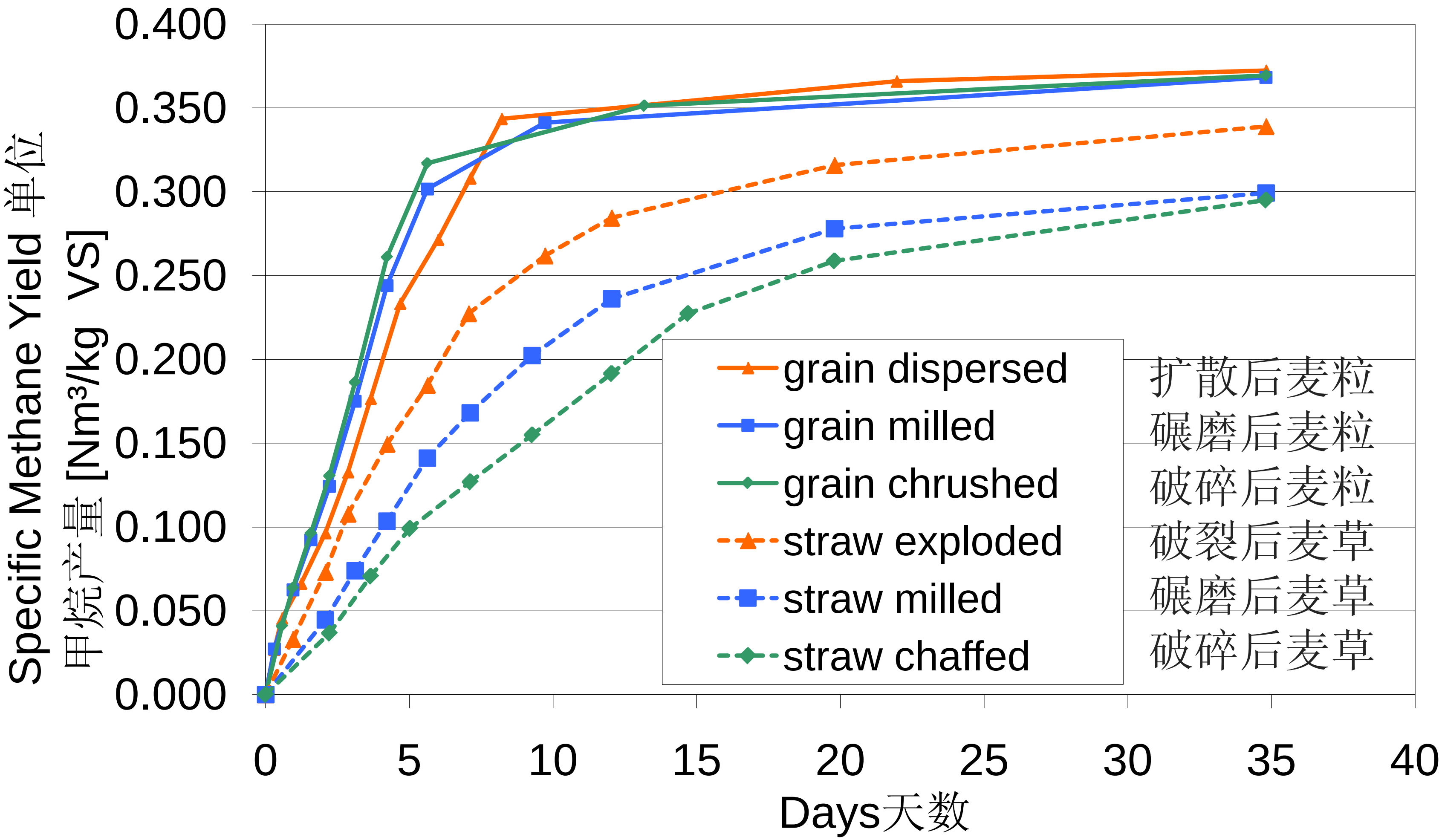
挤压机

Pre-treatment of organic matter - Disintegration – methods
有机物预处理 – 分解 – 方法

Test with triticale as an example for disintegration

以黑小麦作分解测试为例

Pre-treatment of organic matter - Disintegration – methods
有机物预处理 – 分解 – 方法



grain: no effects　　straw: acceleration and rising of degradation

麦粒：无效　　麦草：加速并提高降解率

Pre-treatment of organic matter - Disintegration – methods
有机物预处理 – 分解 – 方法

Hydraulic retention time $\bar{t}$ [d] 水利停留时间	Increase of the biogas formation (from k=0,10 d^{-1} to 0,15 d^{-1}) 沼气产量增加量 $\Delta\dot{V}_{Biogas}$ [%]	
10	+	20
20	+	12,5
30	+	9,1
40	+	7,1
60	+	5
80	+	3,8
100	+	3,1
120	+	2,6

k 反应时间常数，一阶，[d^{-1}]
Us 底物转化 [-]
t 平均水力停留时间[d]

$$U_S = 1 - \frac{1}{1+k\cdot\bar{t}} \quad (1)$$

k reaction time constant, 1. order [d^{-1}]
U_S Substrate´s conversion [-]
$\bar{t}$ mean hydraulic retention time [d]

Conclusion – Disintegration
结论 – 分解

- Disintegration effects differ between batch and continuous tests 序批式和连续反应器分解的效果不同
- Effects are often not provable in large scale continuous tests, also depending on the degradability of the biomass 在连续大规模测试中的效果通常无法证实，也取决于生物质的可降解性
- Easy degradable biomass should not be pre-treated extensive 易降解生物质不应该过分预处理
- The effects are more relevant for biogas plants with short retention times (below 25 days) and slowly degradable 效果通常对于底物降解慢且停留时间比较短的沼气厂更适用
- Case-by-case examination of energy demand (heat and/or power) and costs efficiency are required 需要根据实际情况考虑能量需求（热和/或电）和能效

2.3. Feed in 进料

Classification of Solid Matter Intake into digester
固体物质向消化罐进料方法分类

Direct 直接

1. Screw 螺杆
2. Piston 活塞
3. Wheel loader 装载机

1. Hopper with/ with out integrated infeed
带或不带进料装置的料斗
2. Hopper with pre-treatment device
带预处理装置的料斗

Indirect 间接

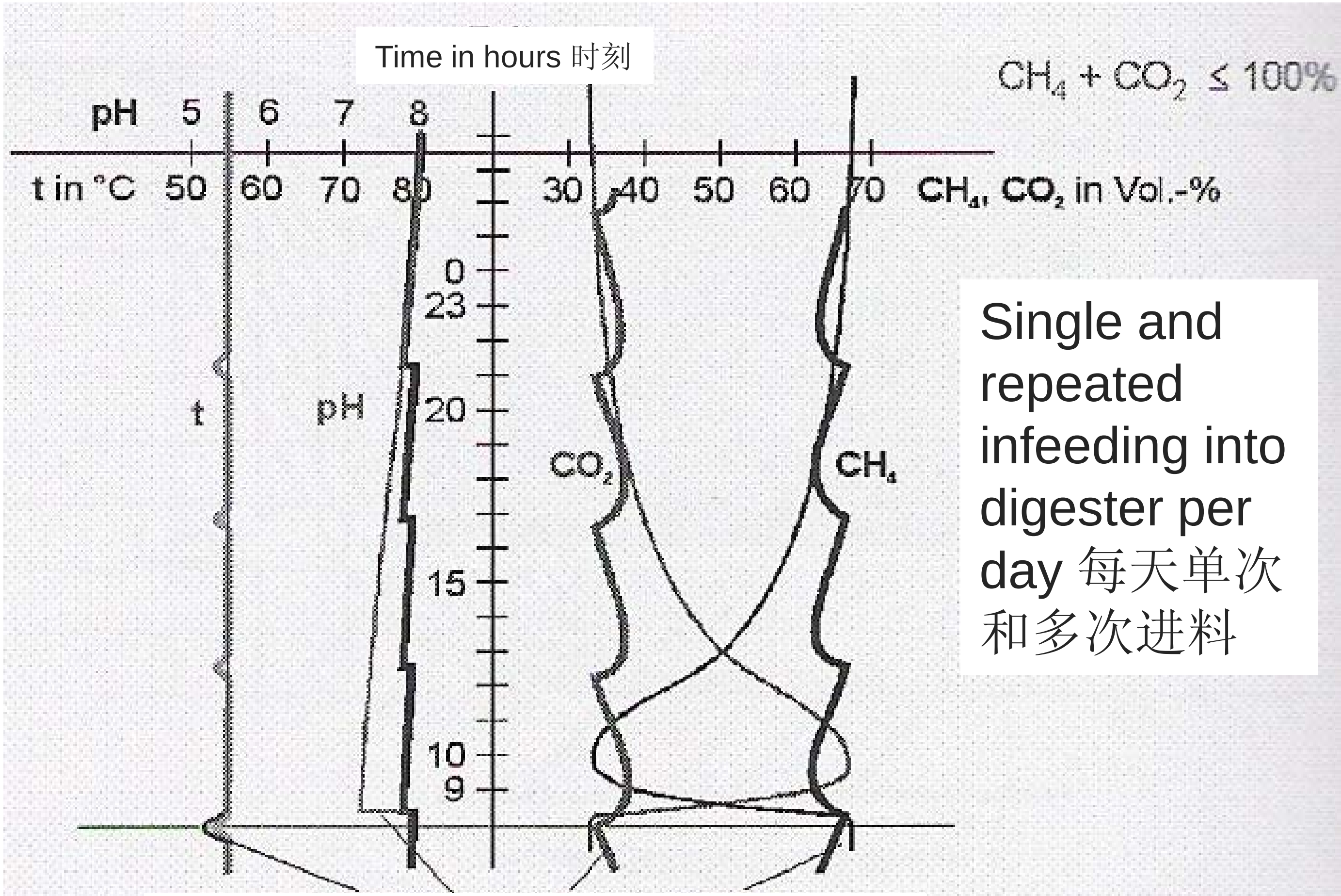
Pump
泵

1. Preliminary tank 预备池
2. In pipeline/ integrated systems/devices 管线/集成系统/装置

1. Hopper with/ with out integrated infeed
带或不带进料装置的料斗
2. Hopper with pre-treatment device
带预处理装置的料斗

DBFZ

Feeding Interval 进料间隔



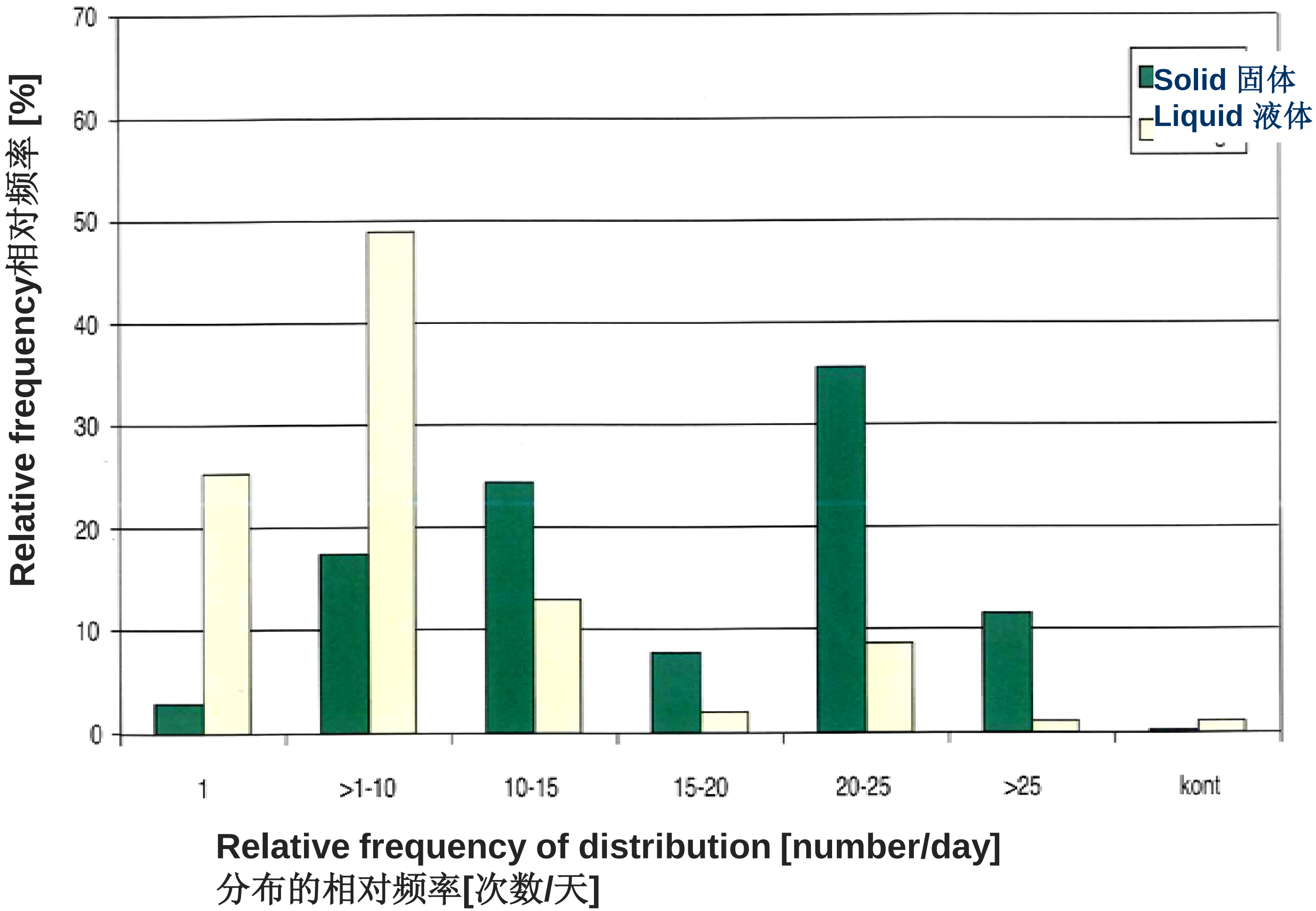
Single and repeated infeeding into digester per day 每天单次和多次进料

Single dosing per day 每天单次进料

Quelle: Langhans 2006, Anaerobe Biologische Abfallbehandlung

Feeding Interval 进料间隔

Relative frequency of distribution of substrat infeed of solids and manure
固体物料和粪便作为底物进料的相对频率



Source: Fachagentur Nachwachsende Rohstoffe (Hrgb): Biogasmessprogramm II; 1. Auflage 2009; ISBN 978-3-9803927-8-5

Feeding Interval 进料间隔

- Aim: constant process conditions 目标：稳定的工艺条件
  - Process stability, high organic load rate 工艺稳定性，高有机负荷
  - High degree of capacity utilization of CHP 高CHP利用率
  - Avoiding of overproduction of biogas 避免过量产气

- Measures: 措施
  - Homogenization of substrate mix 底物搅拌均匀
  - Weighing cells for precise dosing 称重单元以精确进料
  - Increasing of infeed intervals up to 48 intervals per day (quasi continuously) 增加进料间隔到每天48次（近似连续进料）
  - Output-controlled infeed system for constant biogas production (per online-process control) 根据产出控制的进料系统，保证恒定的沼气产量（通过在线工艺控制）

Solid feeder /Infeed systems
固体进料系统

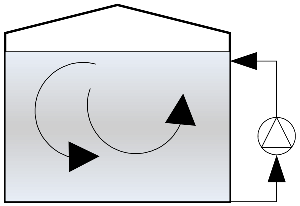
Fotos (v.l.n.r.): Agritechnic Heinrichs GmbH (www.agritechnic.de); Fliegl Agrartechnik GmbH (www.fliegl-agrartechnik.de), Planet Biogastechnik (www.planet-biogas.com)

Fotos (v.l.n.r.): Agritechnic Heinrichs GmbH (www.agritechnic.de); Planet Biogastechnik (www.planet-biogas.com)

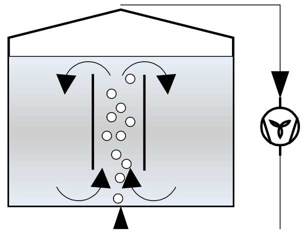
Fotos: Agritechnic Heinrichs GmbH www.agritechnic.de

2.4. Mixing 搅拌

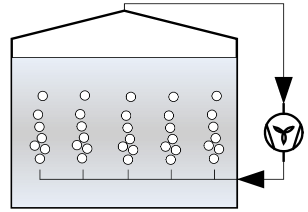
Mixing



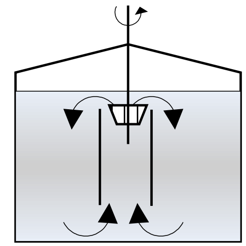
External recirculation
for low DM-content
低固体含量采用外部循环



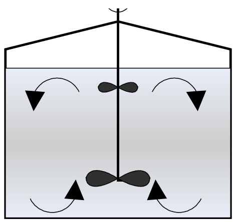
Gas Lift mixing
for low and medium
DM-contents 低和中含固率采用气体提升混合



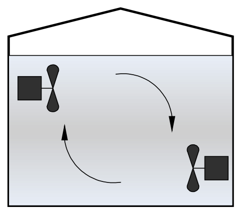
Gas injection
for low DM-content
低含固率采用气体注入混合



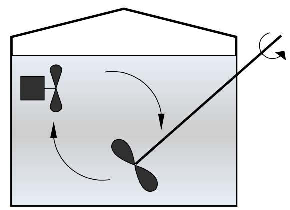
Mammoth-pump
for low and medium
DM-contents 低和中含固率采用超大型泵



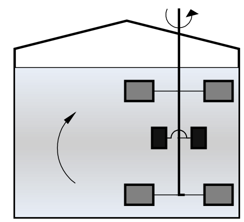
Axial agitator
for medium and high
DM-content中和高含固率采用中央搅拌器



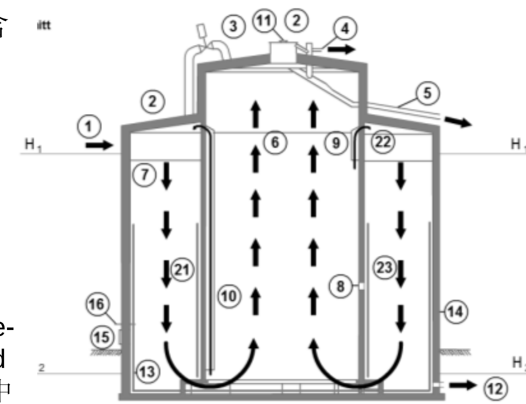
Submercible agitator
for low and medium
DM-contents 低和中含固率采用潜水搅拌器



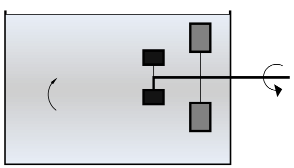
Long shaft agitator
for medium and high
DM-content 中和高含固率采用长轴搅拌器



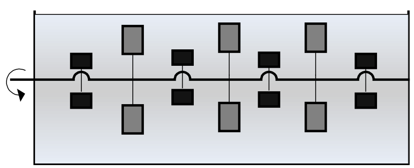
Long shaft agitator (large-winged) for medium and very high DM-contents 中和非常高含固率采用长轴搅拌器（大叶轮）



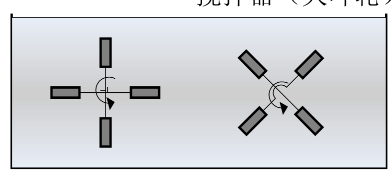
Hydraulic mixing by gas pressure
for low and medium
DM-contents 低和中含固率利用沼气压力水力混合



Large-winged agitator
for medium and very
high DM-contents
中和非常高含固率采用大叶轮搅拌器

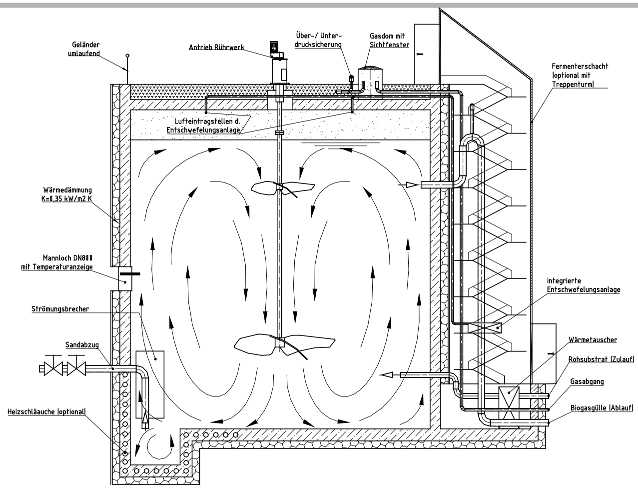


Axial agitator for PFTR
for medium and very high DM-contents 中和非常高含固率PFTR反应器采用轴向搅拌器



Across the plug flow installed agitator for PFTR for medium and very high DM-contents 中和非常高含固率PFTR反应器沿着推流安装搅拌器

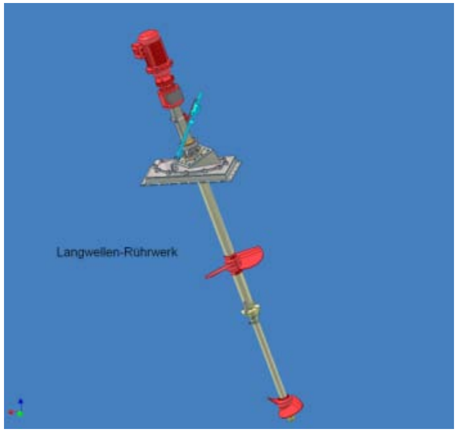
Mixing



Axial agitator; 中央搅拌器
Picture: ENTEC GmbH

Large-winged agitator; 大叶轮搅拌器
Picture: PlanET Energietechnik

Submercible agitator 潜水搅拌器
Picture: Agrartechnik Lothar Becker



Long shaft agitators; 长轴搅拌器
Picture: WELtec BioPower GmbH; Armatec FTS-Armaturen GmbH & Co. KG

Large-winged-submercible agitator
大叶轮潜水搅拌器
Foto: KSB AG

2.5. Gas conditioning/ cleaning
沼气调节/净化

Gas conditioning/ cleaning
沼气调节/净化

Need for gas cleaning 需要沼气净化:

- Biogas contains unwanted associated materials/ substances like water, sulphur or ammonia 沼气含不需要的物质，如水、硫、和氨
- Especially sulphur may cause damages at gas piping system, CHP or Boiler –> CORROSION 特别是硫可能破坏沼气管路、CHP和锅炉—腐蚀

→ **Drainage and gas drying mostly by chiller /cooling unit 沼气干燥和冷凝水去除主要通过冷却单元**

→**Desulphurization (biological, chemical, physical) 脱硫 （生物，化学，物理）**

Gas conditioning/ cleaning

biological, external unit
生物，外部单元

- Desulphurization rates up to 99% 脱硫效率可达99%
- No oxigen intake into digester无需向发酵罐内注入氧气
- Additional investment and maintenance costs额外的投资和维护费用

biological digester internal
生物，发酵罐内部

- Influence on process due to oxygen intake 由于注入氧气影响工艺
- Corrosion at all components in digester head space 发酵罐顶部部件易腐蚀
- Cheap, low maintenance efforts 便宜，维护费用低

Chemical
化学

- No oxygen intake into digerster 无需向发酵罐注入氧气
- Overdosing without problems 过量投加也不会有问题
- Very high Desulphurization rates 极高的脱硫效率
- additional investment and maintenance costs 额外的投资和维护费用

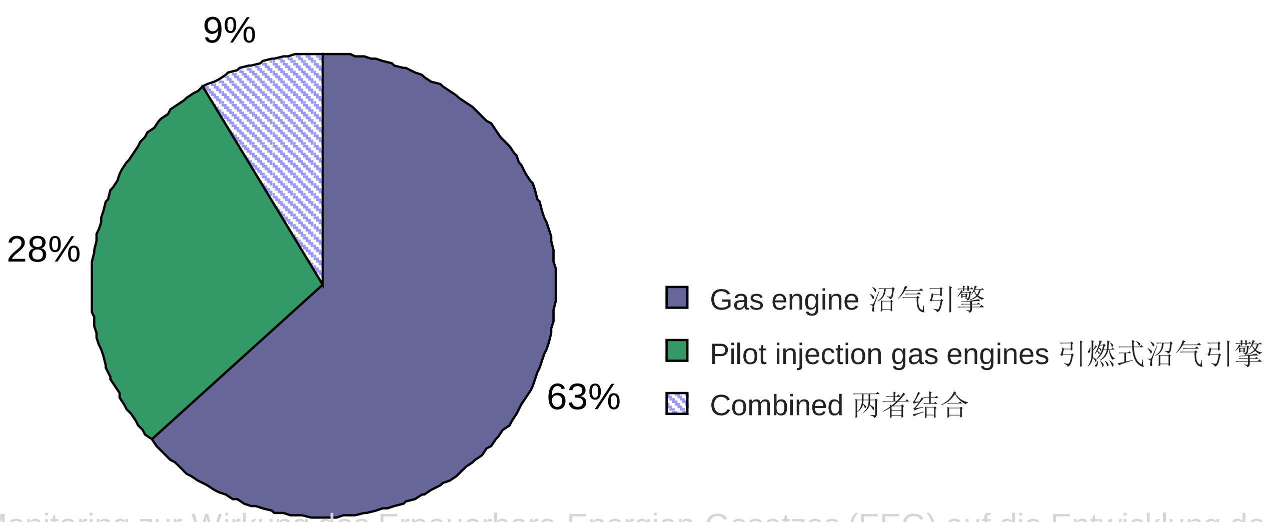
Physical
物理

- Fine desulfurization 精细脱硫
- Purity < 5 ppm possible 可以将硫化氢浓度下降到< 5 ppm
- Very high operating cost 非常高运行费用

2.6. CHP 热电联产

CHP – Development in Germany
CHP – 在德国的发展

- Usage or energy conversion of purified Biogas predominantly via CHP 净化后的沼气主要通过CHP利用和能量转换
- Electrical efficiency increased steadily in the last few years, CHP > 250 kWel with electrical efficiency of > 40 % 在过去数年内发电效率稳定增长， > 250 kWel 的CHP电效率 > 40 %
- Besides CHP (Gas engines and pilot injection gas engines) slightly increased application of gas turbines; Electrical efficiency up to 30 – 32 % 除了CHP（沼气引擎和引燃 式沼气引擎），沼气涡轮机的应用也略有增加，电效率可达到30 – 32 %
- predominantly Gas engine applications (63 %), only 28 % pilot injection gas engines; appr. 9 % of all biogas plants are running with both engines 主要是沼气引擎（63%），只有28%采用引燃式沼气引擎，约9%的沼气厂两者皆有。



n=435

Quelle: Thrän D. et al.: Monitoring zur Wirkung des Erneuerbare-Energien-Gesetzes (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse; 2. Zwischenbericht; Verbundvorhaben im Auftrag des Bundesumweltministeriums, 2010

CHP - Gas engines 沼气引擎

DBFZ

2.7. Biomethane 生物甲烷

Requirements for biogas upgrading to natural gas quality
沼气提纯到天然气品质的要求

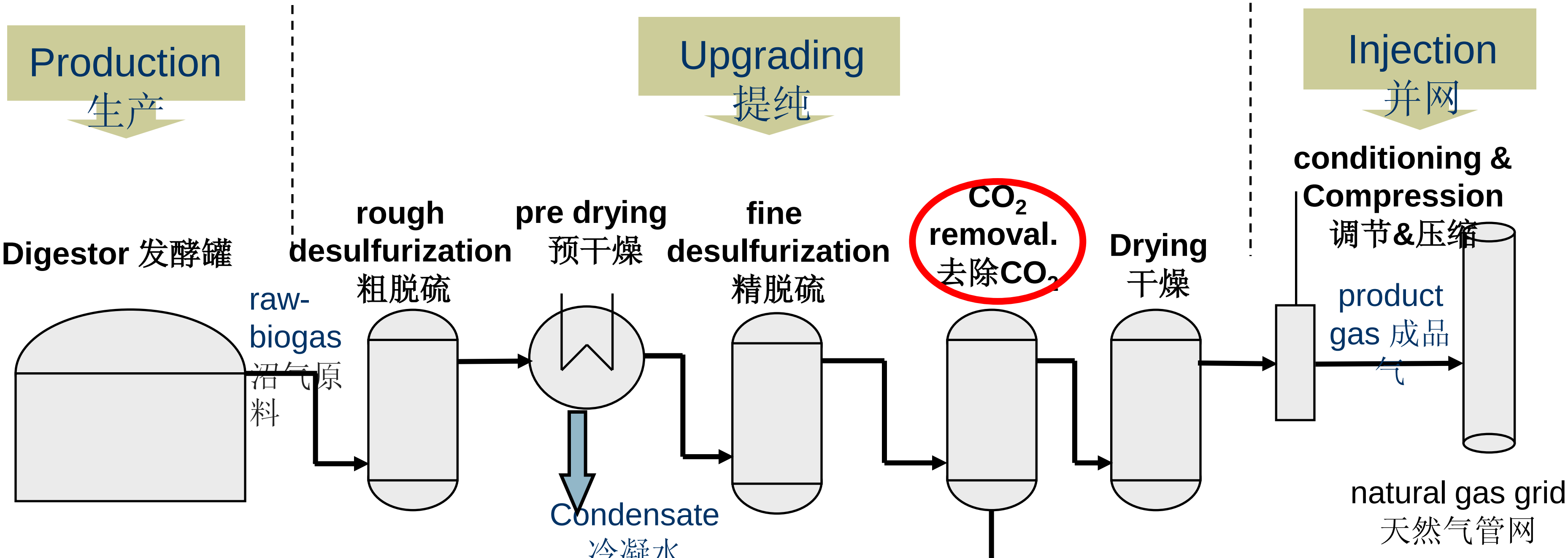
Components 组成	raw biogas 沼气原料	Biomethane 生物甲烷	DVGW 260/262/685
Methane 甲烷	50 - 70 %	90 - 99 %	> 90 % (L-Gas) * > 95% (H-Gas) *
carbon dioxide 二氧化碳	30 - 45 %	1 bis 5 %	< 6 %
Hydrogen 氢气	< 200 ppm	< 500 ppm	< 5 %
Nitrogen 氮气	0 - 2 %	0 - 2 %	k. A.
Oxygen 氧气	0 - 0,5 %	0 - 0,5 %	< 3 % < 0,001 Mol-% *, **
hydrogen sulfide 硫化氢	up to 1000 mg/Nm^3	< 1 mg/Nm^3	< 5 mg/Nm^3
Water 水蒸汽	saturated	< 1 mg/Nm^3	< 200 mg/Nm^3 *, *** < 50 mg/Nm^3 *, ***
upper heating value 高热值	5 - 7 kWh/Nm^3	9,8 - 11,5 kWh/Nm^3	+/- 2 % of H_s in the grid
wobbe index 沃泊指数	5,5 - 10 kWh/Nm^3	10,5 - 15,7 kWh/Nm^3	10,5 – 15,7 kWh/Nm^3

* preversion of DVGW G262 (Entwurf - draft) DVGW G262 初版

** for high pressure grids (> 16 bar), with effects for natural gas storages 高压燃气管网(> 16 bar)，具有天然气储存功能

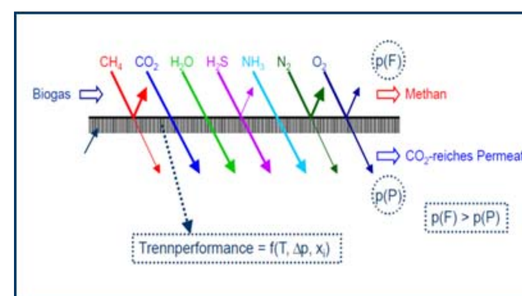
*** for distribution grids (< 16 bar) or rather transportation grids (>16 bar) 燃气供应管网(< 16 bar)或输送管网

Requirements for biogas upgrading to natural gas quality
沼气提纯到天然气品质的要求



Upgrading technologies 提纯技术

- **Water scrubbing 水洗:**
  - Solubility of CO2 against different pressure stages; practical application 不同压力下CO2的溶解度，实际应用
- **Pressure swing adsorption 变压吸附PSA:**
  - Adsorption on molecular sieve or charcoal at high pressure; practical application 分子筛或者活性炭高压吸附，实际应用
- **Amine scrubbing 胺洗:**
  - Dilution of CO2 in scrubbing solution, desorption of scrubbing solution at high temperatures; practical application CO2在溶剂吸收和高温解吸中降低CO2浓度，
- **Membrane technology 膜分离:**
  - Different permeability of different components, first pilot plants 不同成分的不同渗透性，首个中试厂
- **Cryogenic gas separation 液化分离:**
  - Cooling to the evaporating temperature of CO2; research to be done 冷却到CO2的挥发温度，需要更多研究



Technical comparison of the different technologies for upgrading biogas
不同的提纯技术比较

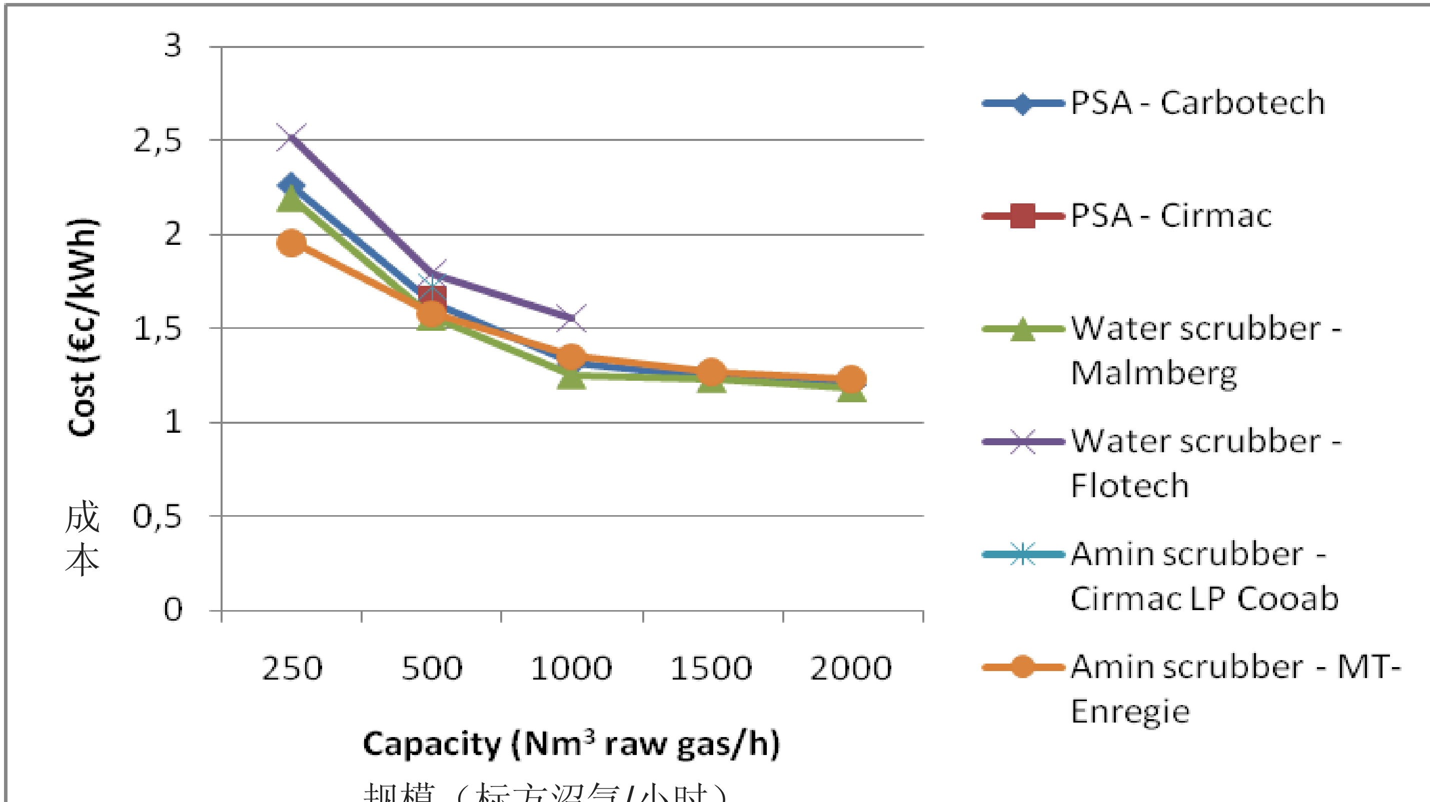
Criteria 标准	PSA	DWW	Genosorb ®	Amine	Membrane
prepurification 预净化	yes	yes/no	yes/no	yes	yes
control range 控制范围	± 10 %	50 – 100 %	50 – 100 %	50 – 100 %	50 –100%
slip of methane 甲烷损失*	2 – 10 %	1 – 2 %	1 - 4 %	< 0,1 %	3 - 5 %
quality of product gas (CH_4) 成品气质量**	> 96 %	> 97 %	> 97 %	> 99 %	92 – 98 %
pressure 压力[bar]	4 – 10	4 – 10	4 – 8	normal pressure 常压	6 – 10
electricity needed 电耗* [kWh/Nm³]	< 0,25	0,2 - 0,3	0,24 - 0,33	< 0,15	0,18 - 0,2
heat needed 热耗 [°C]	no	no	55 – 80 °C	160 °C	no
Chemicals 化学品	no	no	yes	yes	no
References 业绩	> 20	> 25	3	>7	2

* Manufacturers´specification, methane-slip dependend on plant design, on commissioning year and the locations´condition (Carbotech < 3 %, Xebec 4 – 10 %, Malmberg< 1 %, Flotech < 2 %) 制造商规格，甲烷损失取决于设计，调试年限和现场条件

** Methane content oriented on the technical-economical optimum and not technical feasibility (all techniques > 99 %) 甲烷浓度取决于性价比而不是技术可行性（所有技术都可以达到>99%）

Economic comparison of the different technologies for upgrading biogas 不同的提纯技术经济性比较

Specific costs for upgrading biogas to biomethane (including capital costs and costs for operation) 沼气提纯到生物甲烷的单位成本包括初期投资和运行费用）



source: Urban et al., UMSICHT

2. Analysis and evaluation of main state of the art technologies -conclusion
分析和衡量主要先进技术 – 结论

- A broad variety of robust technical solutions are available at the market or under development 大量的可靠技术方案可供选择或者在开发
- Depending on the substrates and the chosen gas utilization, different types of modules (pre-treatment, dosing, digester type, treatment of the residues, gas purification), can be selected/ combined 根据底物和沼气用途，可以选择和结合不同种类的单元（预处理、进料、发酵罐、沼渣沼液处理、气体净化）
- High durability and long intervals of maintenance lead to operating and full load hours 高耐久性和长维护间隔才能长时间高负荷运行
- Further optimization of the biogas technologies concerning the reduction of losses and a decline of the internal energy consumption are desirable 沼气技术将来的优化主要在于减少损失和降低厂内能耗
- Measuring devices are essential to control and evaluate biogas plants 测量装置是控制和衡量沼气厂的关键

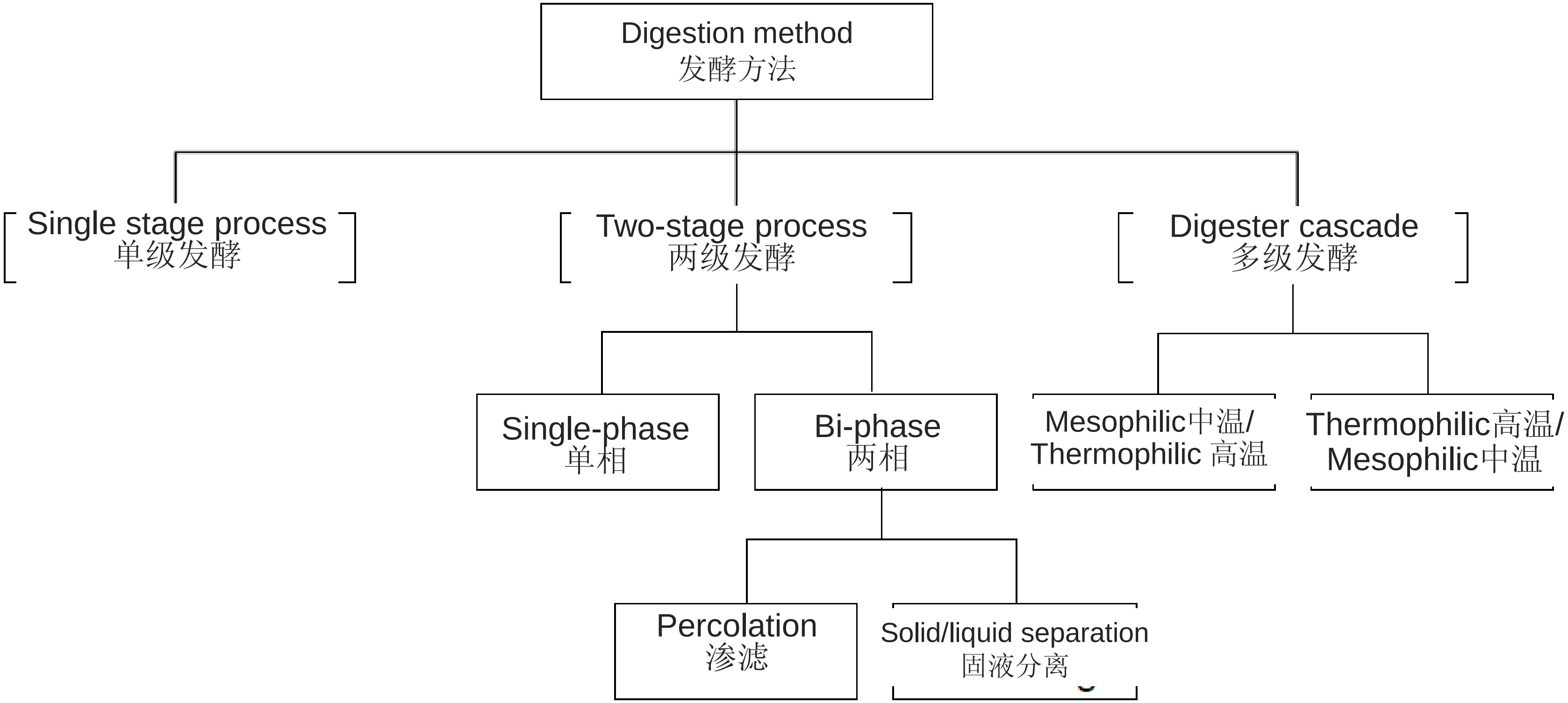
3. ASSESSMENT / EVALUATION OF THE OVERALL BIOGAS PLANT CONCEPT
评价/衡量沼气厂的整体概念设计

Process variant – Systematization
工艺变量 – 系统化

Digesting process/ technique 发酵工艺/技术

Differentiating factors 不同因素	Decition criteria 选择标准	Process options 工艺选择
Dry matter content 干物质含量	Dry matter content in digester 发酵罐内干物质含量	a. Wet fermentation 湿式发酵 b. Solid state fermentation 干发酵
Kind of Infeed 进料方式	Continuity of infeed 进料连续性	a. Discontinuously 不连续 b. Semi-continuously 半连续 c. Continuously 连续
Digestion temperature 发酵温度	Substrate composition 底物组成 Need of sanitation 杀菌的需要	a. Psychrophilic 常温 b. Mesophilic 中温 c. Thermophilic 高温
Kind of mixing 混合方式	Ensuring of minimum retention time, substrate, dry matter content 确保最小的停留时间，底物，干物质含量	a. Completely stirred 全混 b. Plug flow 推流 c. Not stirred 不混合
Fixing of active biomass 活性污泥固定	Danger of washing out of activated biomass 活性物质被带走的危险	a. With biomass-retaining 带污泥固定 b. Without biomass-retaining 无污泥固定
Process separation 分级工艺	Completeness of degradation, substrate composition, acidification affinity 降解率，底物组成，易酸化性	a. Singlestage 单级 b. Multistage 多级 c. Single-phase 单相 d. Biphasic 两相

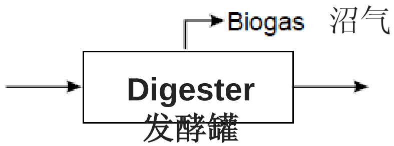
Systemization of digesting processes
发酵工艺系统化



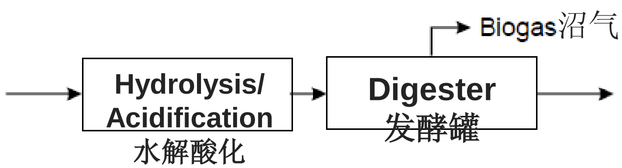
Picture after: Weiland, P.: Biologie der Biogaserzeugung; Institut für Technologie und Biosystemtechnik der Bundesforschungsanstalt für Landwirtschaft (FAL); ZNR Biogastagung, Bad Sassendorf-Ostinghausen, 02.04. 2003

Schematic presentation of various fermentation methods
不同发酵方法的示意图

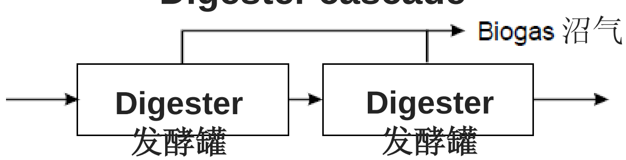
单级发酵
Single stage process



两级发酵
Two-stage process

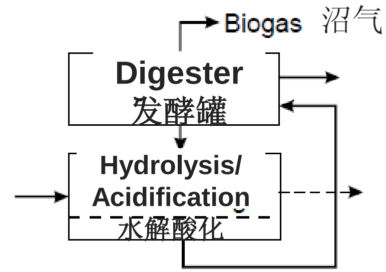


多级发酵
Digester cascade

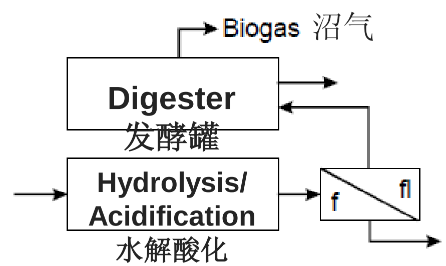


两相两级发酵
Bi-phasic Two-stage process

a) Percolation 渗滤



b) Solid / liquid separation



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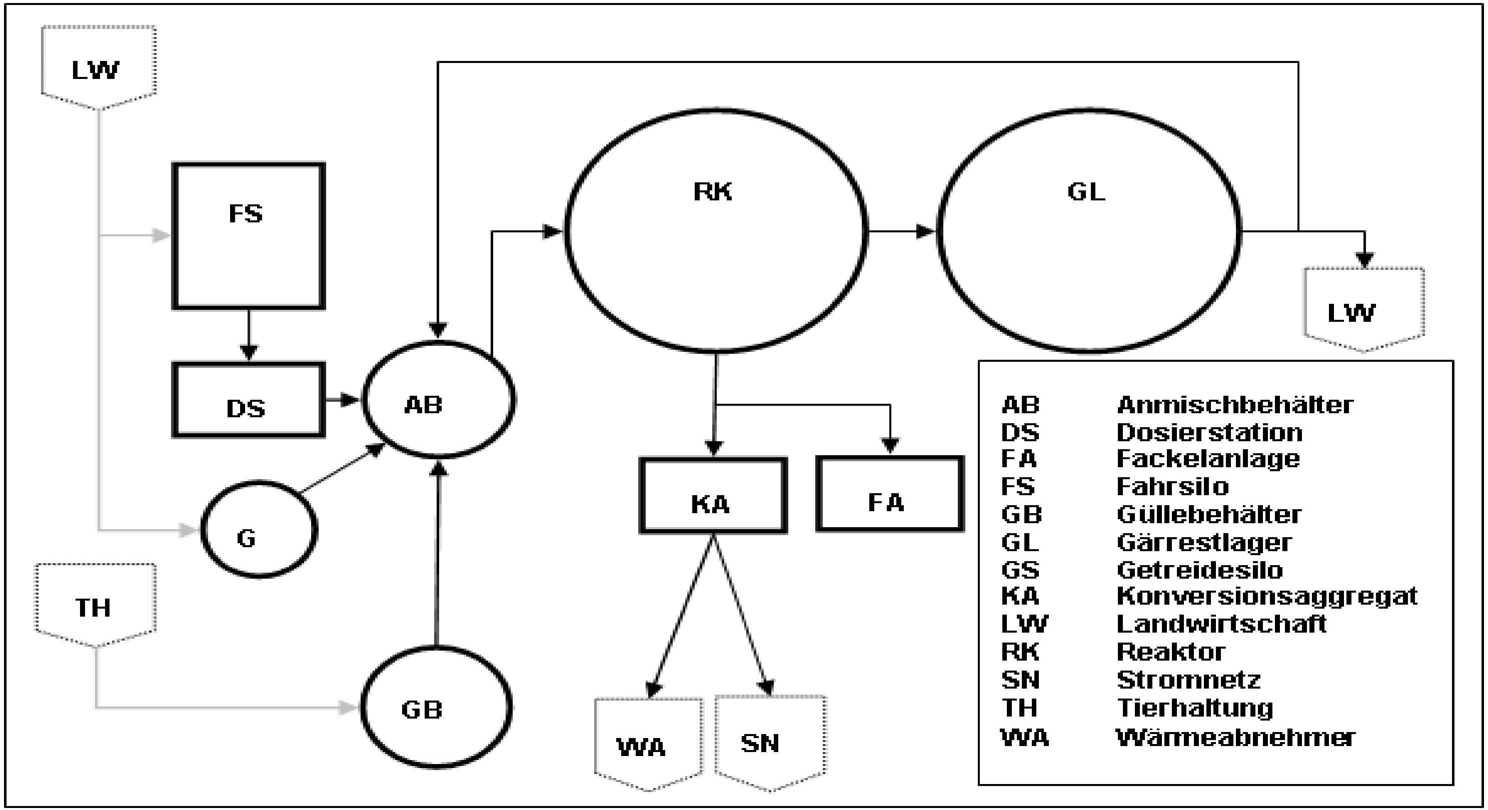
Application typical farm-scale digestion of Energy crops
典型农场规模能源作物厌氧发酵应用

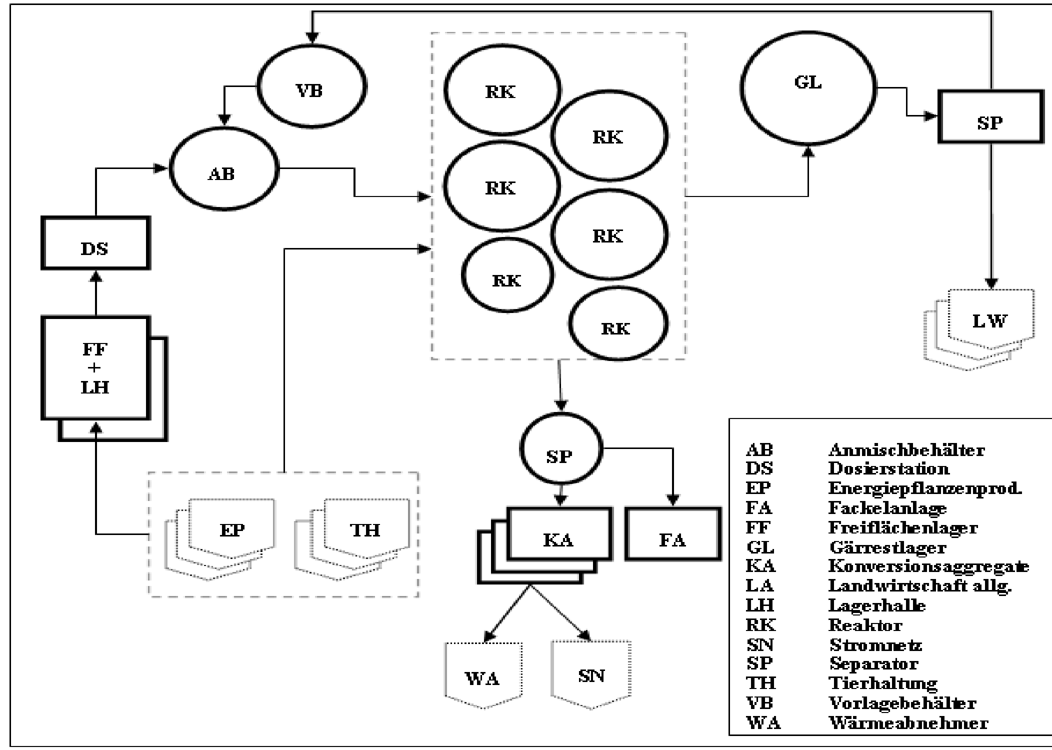
- farm-scale, single step 农场规模，单级
- startup 10/2005 2005年10月启动
- inst. CHP capacity 500 kW_{el} 装机功率500 kW
- approx. 12.000 t Substrates y^{-1} 每年处理约12,000 底物
- approx. 2.500m^3 Digester volume 约2,500方发酵罐容积

- Energy crop acreage ~ 250 ha 能源作物面积约250公顷
- Substrates: corn silage, liquid manure, rye 底物：玉米青贮、液态粪污、黑麦
- Participant on scientific evaluation programme 科学评估计划参与单位



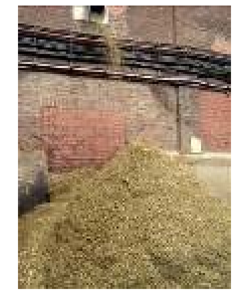
Application industrial-scale digestion of Energy crops
典型工业规模能源作物厌氧发酵应用

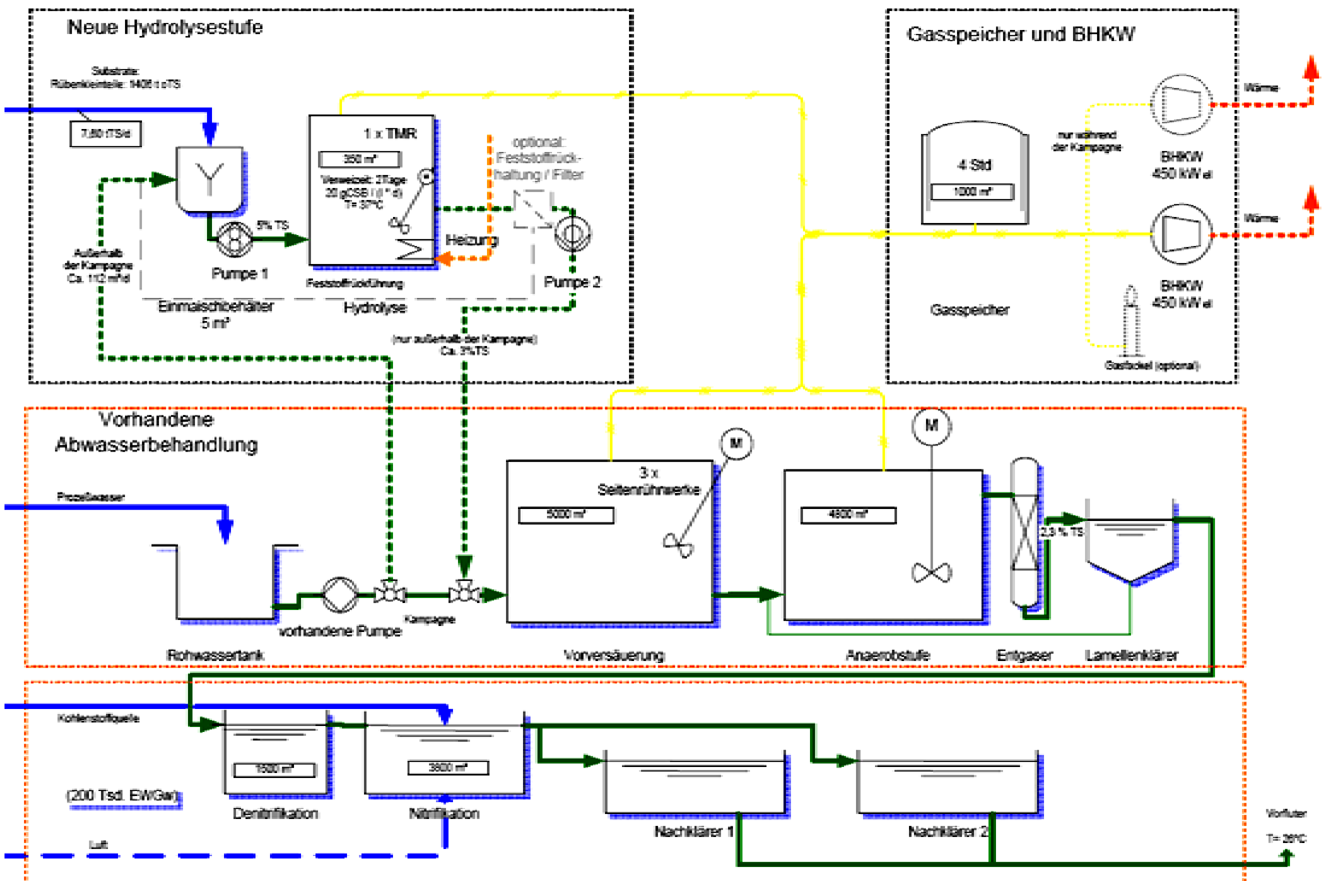
- startup 12/2004 2004年12月启动
- 3 engines, total inst. capacity 4.2 MW_{el} 三台发电机，总装机容量4.2MW
- excess heat used for industrial process 过量的热用于工业应用
- approx. 70.000 t substrates y^{-1} 每年处理约70,000吨底物
- Approx 17.000m^3 digester volume 发酵罐容积约17,000方
- 24h hydrolysis step 先水解24h
- originally two-step process, now parallel single-step digestion in 4 fermenters and 2 smaller stores 四个发酵罐和两个小储罐最开始采用两级工艺，现在两个并联单级发酵
- acreage ~ 1.500 ha / 60 suppliers 60个供应商共约1,500公顷
- separation of effluent 沼渣沼液分离
- substrates: silages and grist from different crops, CCM, grass and other 底物：不同作物的青贮和壳，CCM，草和其他



Application sugar industry 制糖业应用

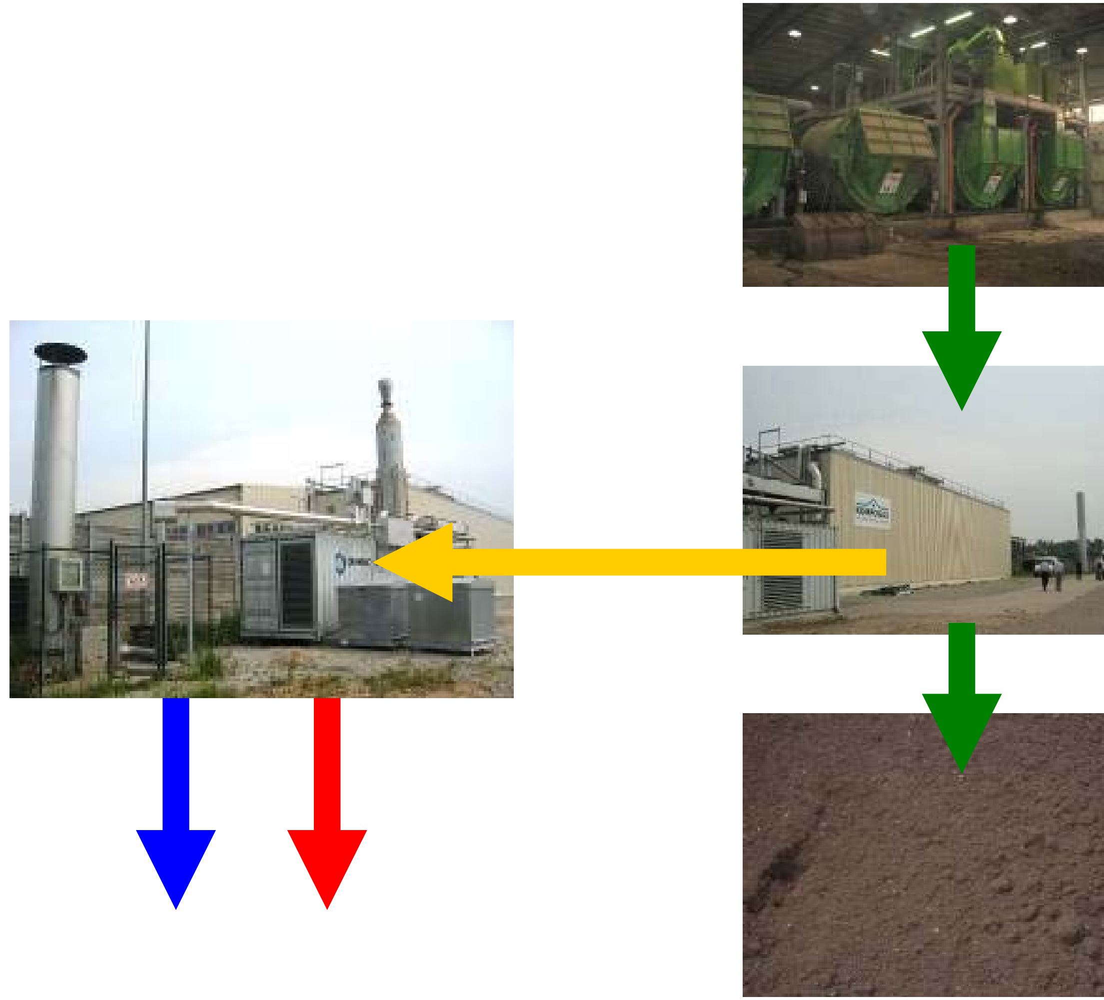
- Byproducts from sugar beet processing 甜菜加工副产物
- Anaerobic treatment of waste-water only 3-4 mon/y 废水厌氧发酵每年只有3-4个月
- AD-technology and know-how from over 20 years 超过20年的厌氧发酵技术和技能
- Fast and stable process 快速和稳定的工艺





Application Digestion of Biowaste
生物垃圾发酵应用

- Dry Fermentation of biowaste 生物垃圾干式发酵
  - biowaste 24.000 t/yr 生物垃圾24,000 吨/年
  - Aerobic pretreatment 好氧预处理
  - Plug-Flow-Reactor 推流式反应器
  - Composting of effluent 发酵残余物发酵
  - CHP-device 热电联产
  - Complete housing/low odour emissions 完全室内/低臭气扩散



Process Control – Process Target
工艺控制 – 工艺目标

Definition process target: Maximum gas production
定义工艺目标：产气量最大化

→ Influenced by substrate quality, degradation rate, disturbances of biological process or technical equipment, internal energy demand, losses and emissions
受底物质量，降解速率，干扰物或者技术设备，内部能耗，损失和排放影响

reliability/ optimization
可靠/优化

Disturbances
干扰

Biology 生物学

Stable processing 稳定的工艺过程
Degradation optimization 降解过程优化

Technical equipment
技术设备

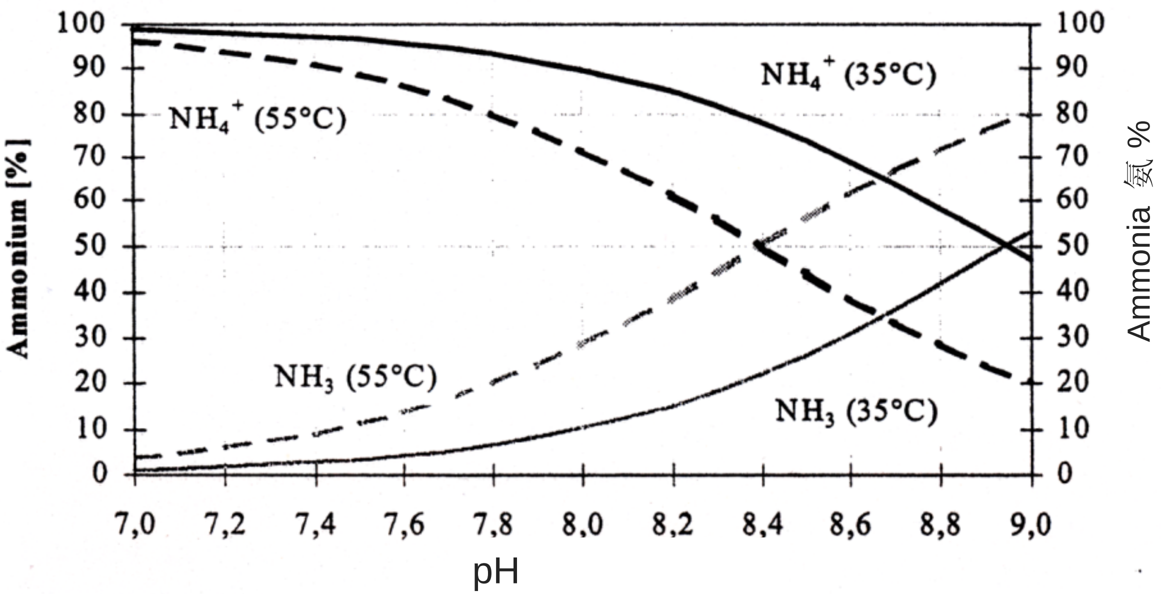
Cogeneration unit 发电单元
Mixer etc. 搅拌器等

Control of Biological Process
生物过程控制

Causes for biological problems 导致生物问题的原因:

- Ammonia Toxicity (nitrogen content of feedstock too high) 氨毒性（进料的氮含量过高）
- Soluble Sulfide Toxicity 溶解性硫化物毒性
- Inorganic Salt Toxicity (sodium, potassium, calcium, magnesium) 无机盐毒性（钠、钾、钙、镁）
- Antibiotics 抗生素
- Unstable Temperature 温度波动
- pH-value low or high pH值过高或者过低
- Foam 泡沫
- Overloading (OLR too high) 过载（有机负荷过高）
- Retention time too short 停留时间过短
- Volatile Fatty Acid Accumulation (result) 挥发性脂肪酸累积（后果）

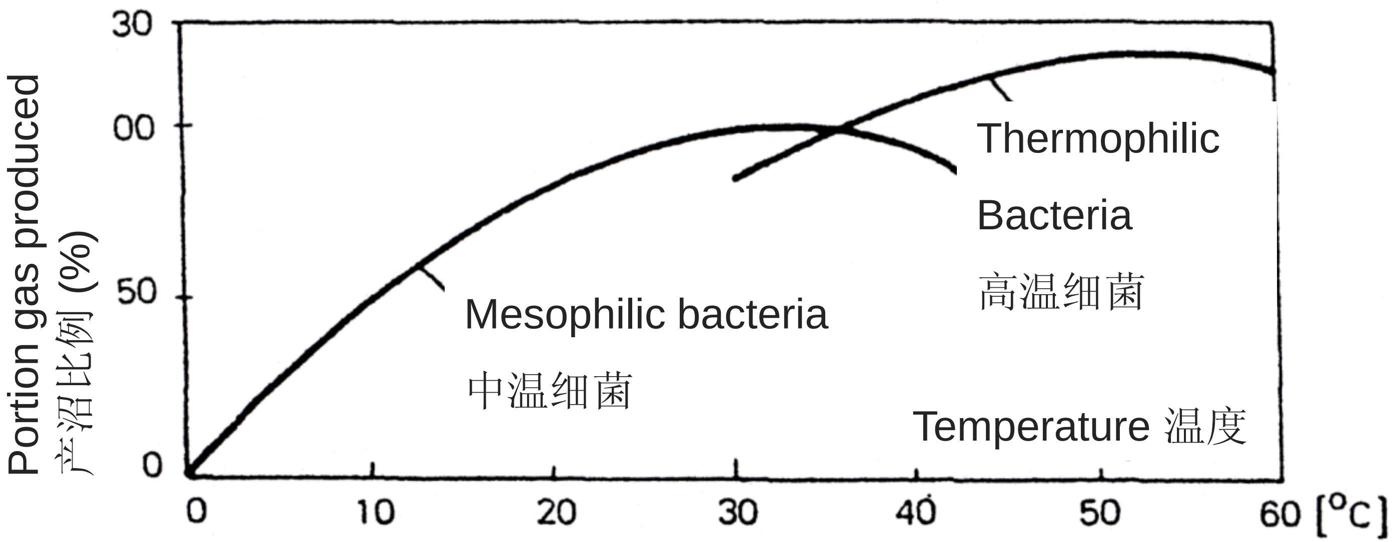
Example: Ammonia toxicity 示例：氨毒性



Nitrogen rich feedstock 氮含量高原料

Ammonium is formed 形成胺

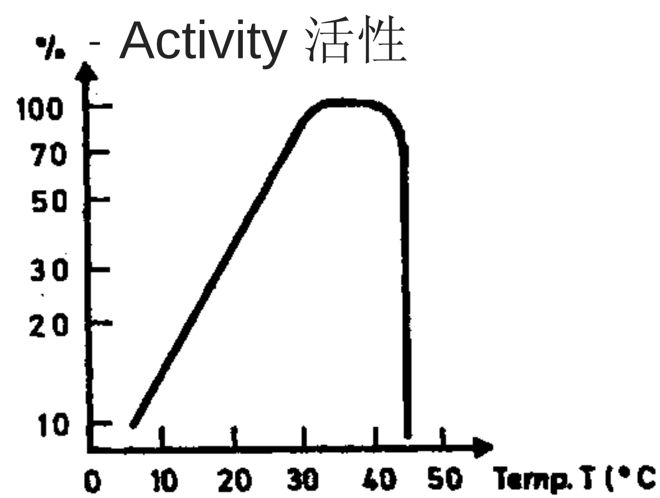
Example: Temperature 示例：温度



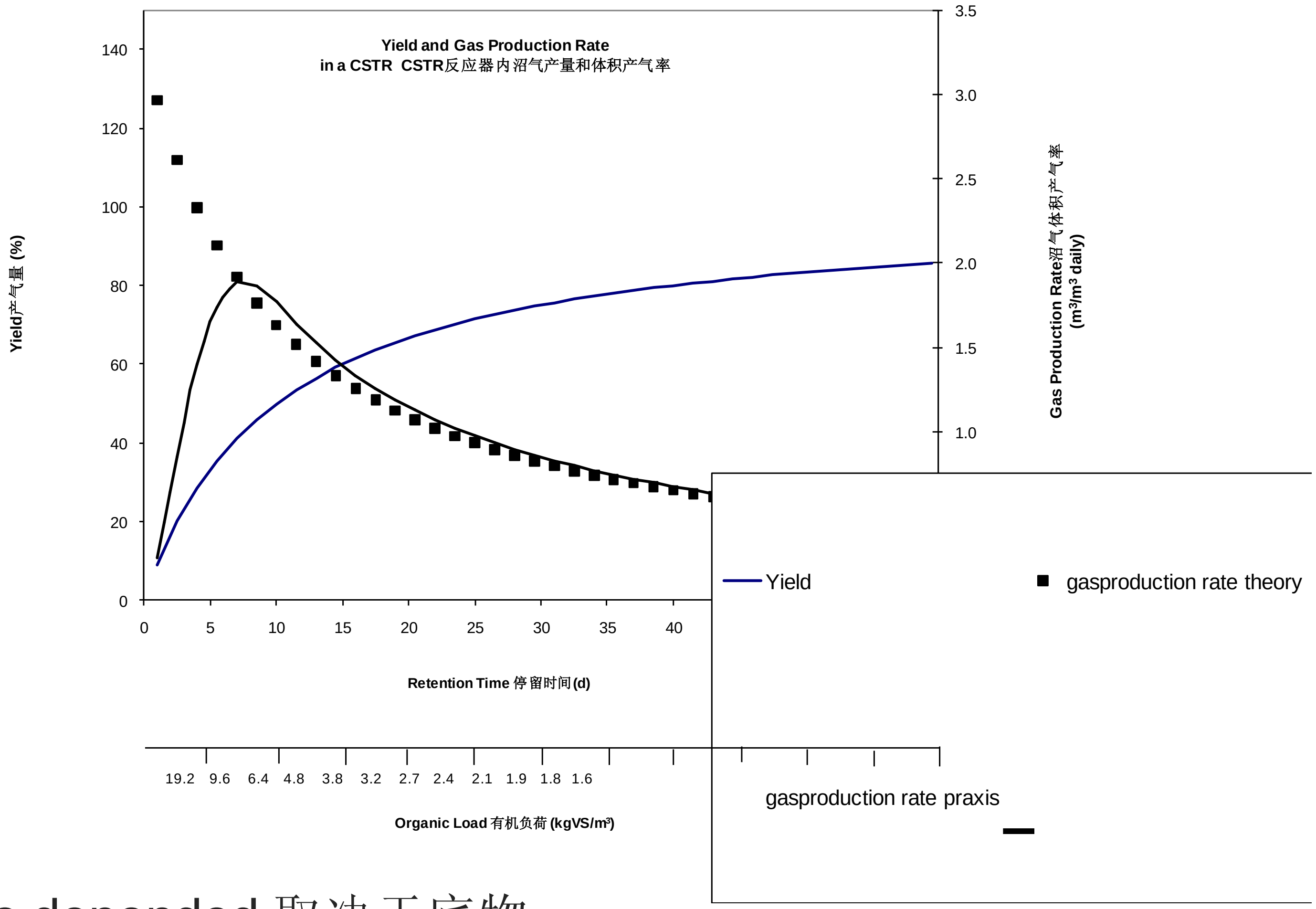
Optimal 最优:

Mesophilic中温: 35-40 °C

Thermophilic高温: 55 °C



Example: Retention Time/ Organic Load (Yield and reactor utilization) 示例：停留时间/有机负荷（产气量和反应器利用率）



Substrate depended 取决于底物

Crucial for plant design and economics 对沼气厂设计和经济效益至关重要

Process evaluation 衡量工艺

Laboratory tests 实验室测试

- Degradation of VS, TS, TOC, COD VS, TS, TOC, COD的降解
- Content of organic acids (sum parameter) 有机酸浓度（合计）
- Content of organic acids (portion of each acid)有机酸浓度（各种酸比例）

➢not permanent available 不是永远有

➢need of sampling 需要采样

➢time consuming, 耗时

➢difficult to automate, 难以自动化

➢high information content 高信息含量

Online measurement 在线监测

- Input 进料
- Gas production rate 沼气产率
- pH-value pH值
- Methane content 甲烷含量
- Carbondioxid content 二氧化碳含量
- Hydrogen content 氢含量
- Temperature 温度

➢Permanent available, 永远有

➢easy integration to automated process 易于集成到自控系统

➢information content??? 信息含量？？？

3. Assessment / Evaluation of the overall biogas plant concept - conclusion
评价/衡量沼气厂整体概念设计

- Are technology and substrates (texture/amount) a good match? 技术和底物（材质/数量）是否匹配？
- Which ratio of energy production to energy consumption is achievable? (electricity and heat)可以达到何种能量利用比例？（电和热）
- Fits the plant to operational needs, infrastructure and consumers - gas, electricity and/or heat grid? 让沼气厂适应运行、基础设施和用户需要，燃气、电和/或供热网络
- Are collection and documentation of data appropriate to avoid malfunction? 数据收集和记录是否可以避免误操作?
- Are the losses reduced to a minimum? 损失是否降到最小?
- Which climatic conditions are to consider? Are insulation or cooling needed? 考虑到是那种气候条件，是否需要隔热或冷却?
- Are the distances between biogas plant and substrates source respectively between biogas plant and residues application short enough? (logistics, costs) 沼气厂和底物来源之间，沼气厂与沼渣沼液施用地之间距离是否足够近（物流费用）?
- Are aspects of environmental protection to consider? 是否考虑环境保护措施？

4. THEORETICAL ENERGY OUTPUT AS BASIS FOR THE BIOGAS PLANT EVALUATION 理论能量产出作为衡量沼气厂的基础

DBFZ

Requirements for energy balances as basis for efficiency evaluation 能量平衡的需要作为衡量能效的基础

- Efficiency: Ratio of actual power output and power input 能效：实际能量产出和能量输入的比例
- What is necessary for a qualified evaluation? 需要什么来做合格的评估

1. Definition of theoretical energy output 定义理论能量产出
2. Evaluation, documentation, quantification of mass and energy streams,

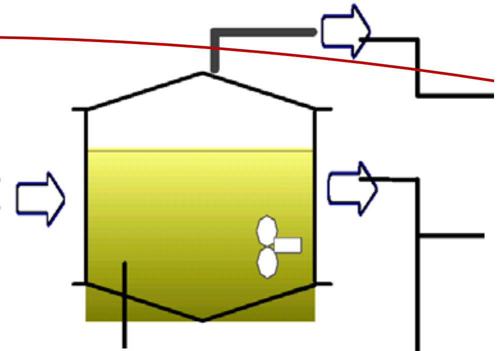
   Evaluation of operational hours, (documentation of down times, flaring events, maintenance periods etc.) 衡量、记录和量化物质和能量流。衡量运行时间（记录停机时间，火炬燃烧和维护期）
3. Calculation of capacity utilization 计算容积利用率
4. Actual – theoretical comparison 实际-理论结果比较
5. Identification of bottlenecks 确定瓶颈
6. Optimization 优化

Calculation of theoretical energy output 理论能量产出计算

Basic parameters 基本参数

Input quantity 输入量 $\left(\frac{m^3}{d}\right)$

Input concentration 输入浓度 $c_0\left(\frac{kg}{m^3}\right)$



Reactor volume 反应器容积 $V_R\left(m^3\right)$

Biogas quantity 沼气量 $Q_B\left(\frac{m^3}{d}\right)$

Outflow quantity 出料量 $Q_A\left(\frac{m^3}{d}\right)$

Outflow concentration 出料浓度 $c_A\left(\frac{kg}{m^3}\right)$

Process parameters 工艺参数

Hydraulic retention time 水利停留时间 $t_m = \frac{V_R}{Q_0}(d)$

Organic load 有机负荷 $B_R = \frac{Q_0 \cdot c_0}{V_R} = \frac{c_0}{t_m}\left(\frac{kg}{m^3 \cdot d}\right)$

Performance parameters 性能参数

Biogas yield 沼气产量 $y_B = \frac{Q_B}{Q_0 \cdot c_0}\left(\frac{m^3}{kg}\right)$

Biogas rate 容积产气率 $r_B = \frac{Q_B}{V_R} = y_B \cdot B_R\left(\frac{m^3}{m^3 \cdot d}\right)$

Source: Grund- und Bemessungsparameter landwirtschaftlicher Rührkesselreaktoren (Linke et al. 2003)

Definition of theoretical output: Calculation of Gas yield
定义理论输出量：计算沼气产量

计算沼气产量，能量含量，和通过CHP可产生能量和热

Calculation of biogas amount, energy content and producable energy and heat via Combined heat and power plant

底物 **Substrate**	进料量 **Fresh matter Quantity**	干物质含量 **Dry Matter Content (DM)**	**Organic Dry Matter Content (oDM)**	有机干物质量 **oDM-Quantity**	沼气产量 **Biogas yield**		甲烷浓度 **CH4-concen-tration**	甲烷能量 **Energy yield CH4**	沼气能量 **Energy content in Biogas**
	t/a	%	% DM	t/a	m³/t oDM	m³/a	%	kWh/m³	kWh/a
Cattle manure 牛粪	18.250	10%	78%	1.424	250	355.875	60%	9,97	2.128.844
Maize silage 玉米青贮	1.095	30%	90%	296	550	162.608	52%	9,97	843.022
Average substrate mix 混合物		**11%**	**79%**		**302**		**57,5%**		
Sum Substrate mix 合计混合物	**19.345**			**1.719**		**518.483**		**9,97**	**2.971.867**

oDM [t/a] = Fresh matter 干物质 [t/yr] x DM [%] x oDM [%]

Biogas yield沼气产量 [m³/a] = oDM [t/yr] x Biogas yield沼气产量[m³/t_{oDM}] (see also section 1 and 2 参见第1，2部分)

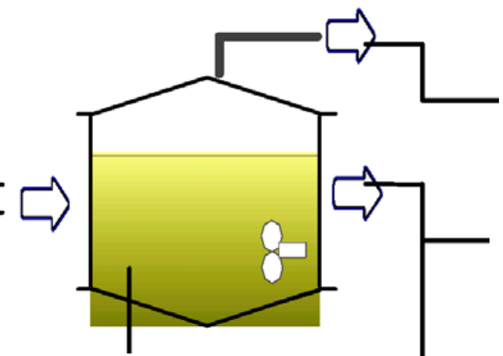
Energy content Biogas 沼气能量含量= Biogas yield 沼气产量[m³/t_{oDM}] x CH_4-Conc. 甲烷浓度[%] x Energy yield CH_4甲烷能量产出[kWh/m³]

Operating parameters – Overview
运行参数 – 一览

Basic parameters 基础参数

Input quantity 进料量 $\left(\frac{m^3}{d}\right)$

Input concentration 进料浓度 $c_0\left(\frac{kg}{m^3}\right)$



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Performance parameters 性能参数

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Source: Grund- und Bemessungsparameter landwirtschaftlicher Rührkesselreaktoren (Linke et al. 2003)

Calculation of theoretical energy yield
理论能量产出计算

计算沼气产量，能量含量，和通过CHP可产生能量和热

Calculation of biogas amount, energy content and producable energy and heat via Combined heat and power plant

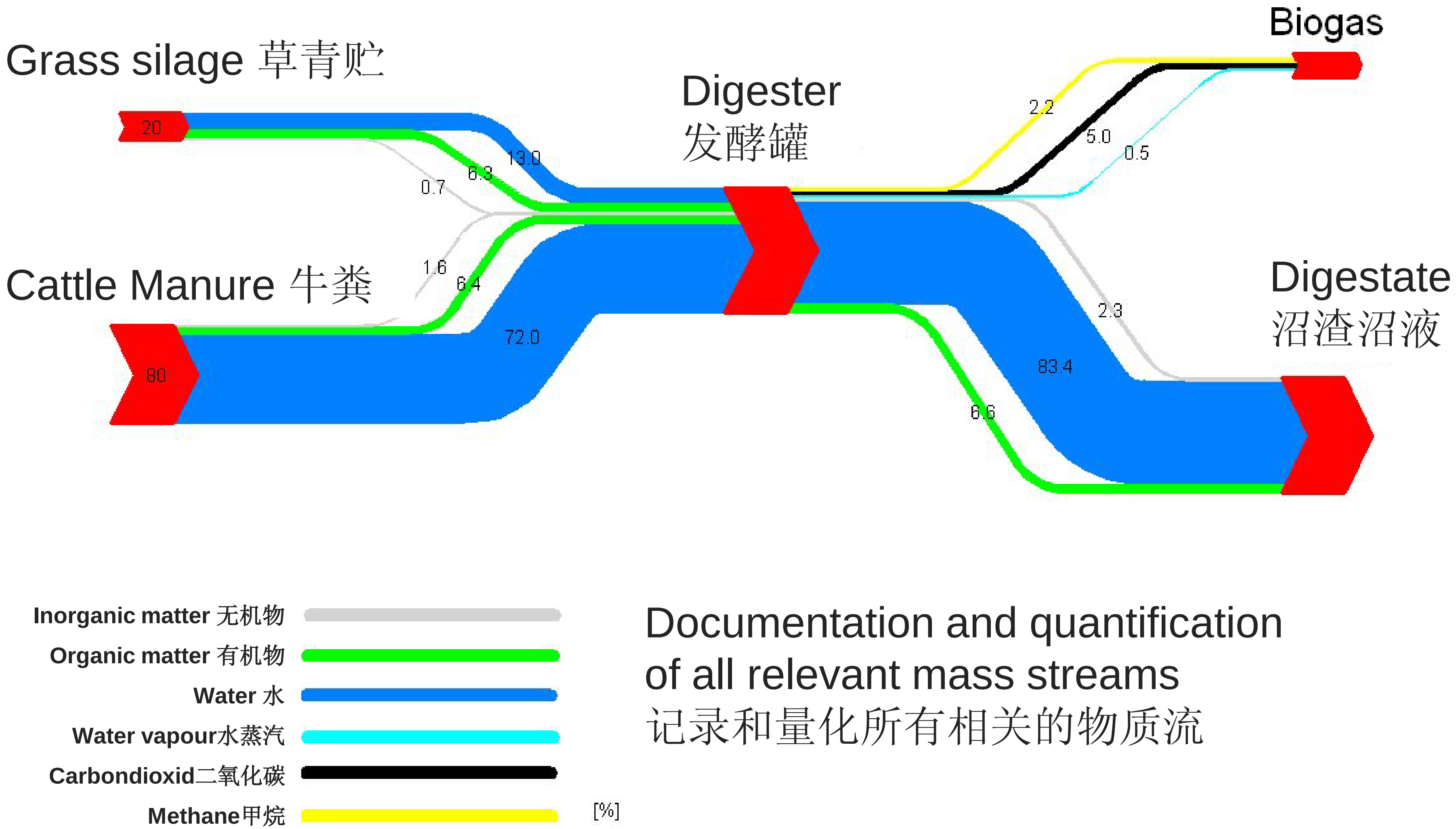
底物 Substrate	进料量 Fresh matter Quantity	沼气能量含量 Energy content in Biogas	电效率 Electrical Efficiency	电能 Electrical Energy	热效率 Thermal efficiency	热能 Thermal Energy	满负荷运行时间 Full Load Hours at 100% Capacity	CHP容量 Electrical Capacity CHP	CHP热容量 Thermal Capacity CHP
	t/a	kWh/a	%	kWh/a	%	kWh/a	h/a	kW	kW
Cattle manure 牛粪	18.250	2.128.844	40%	851.538	45%	957.980	7500	114	128
Maize silage 玉米青贮	1.095	843.022	40%	337.209	45%	379.360	7500	45	51
Average substrate mix 混合物			**38%**		**45%**		**7500**		
Sum Substrate mix 合计混合物	**19.345**	**2.971.867**		**1.188.747**		**1.337.340**		**158,5**	**178,3**

Available thermal energy CHP CHP可用热能

Available electricity CHP可用电能

Available thermal energy boiler 锅炉可用热能

Mass balance 物料平衡



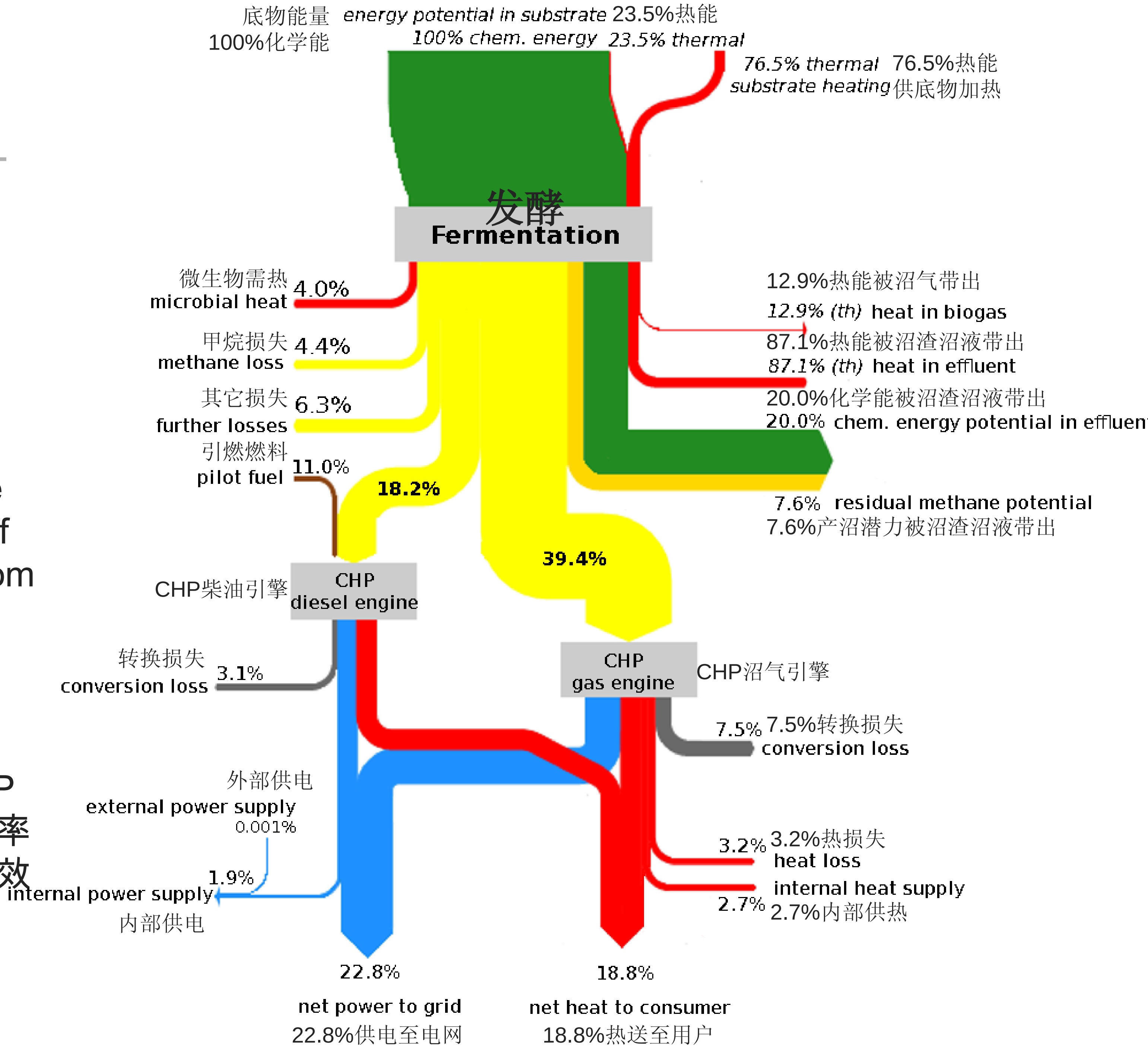
Documentation and quantification of all relevant mass streams
记录和量化所有相关的物质流

Mass balances evaluation
衡量物料平衡

- Does the quality and amount of input masses realized in practice meet the design assumptions? 输入物料的数量和质量实际是否符合设计值
- Is the Biogas production according to the theoretical value? 沼气产量是否符合理论值(consider the conversion efficiency within the CHP as important factor if no direct quantification of the biogas mass flow is available!!) 如果没有直接量化沼气产量，则一定要考虑CHP的转换效率
    - If not check: 如果没有检查
        - Substrate quality (is the assumed biogas potential correct?) 底物质量（设计的产沼潜力是否正确？）
        - Infeed amount correct? 进料量是否正确？
        - Quantification of degree of degradation by means of a gas potential test of the digestate 通过沼渣沼液产沼潜力实验量化降解率
        - Stability of biological process (acid concentration?) 生物过程（酸浓度）的稳定性
        - Temperature 温度
        - Inhibition effects 抑制效果
        - Leackage of biogas within the gas collection system 沼气收集系统的泄漏

Energy balance 能量平衡

A high degree of utilization of waste heat from the CHP is of enormus relevance for the overall efficiency CHP
废热的高利用率对于整体能量效率至关重要



Energy balance evaluation
衡量能量平衡

- Is the energy output as expected? 能量产出是否达到设计值？

- Electrical: 电力
- If not check: 如果没有记录
  - Biogas production as assumed? 沼气产量是否达到设计值？
  - CHP unit – conversion efficiency as assumed? CHP的转换效率是否达到设计值？
  - Consumption of devices on site to large? 现场设备的电耗是否过大？
  - Downtime - what are bottlenecks of the process? 停工 – 工艺瓶颈在哪儿？
- Thermal: 热能
- If not check: 如果没有记录
  - Losses due to poor insulation? 保温太差导致的热损失？
  - Are there other options for heat utilization? 有没有其它利用热的途径？

4. Theoretical energy output as basis for the biogas plant evaluation – conclusion 理论能量产出作为衡量沼气厂的基础 – 结论

- Energy output depended on many factors (substrate qualities, stability of biological process, efficiencies and availabilities technical devices) 能量产出取决于许多因素（底物质量、生物过程的稳定性、技术设备的效率和可利用率）
- Primary target should be: process stability, reliability of technology 主要目标应该是：工艺稳定，技术可靠
- Secondary target: gas production rate and energy output 次要目标： 产气率和能量产出
- The energy consumption of all devices should be kept by a minimum 所有设备的能耗应该尽量最小
- A high degree of utilization of waste heat from the CHP is of enormus relevance for the overall efficiency CHP废热的高利用率对CHP整体的整体效率有巨大影响。

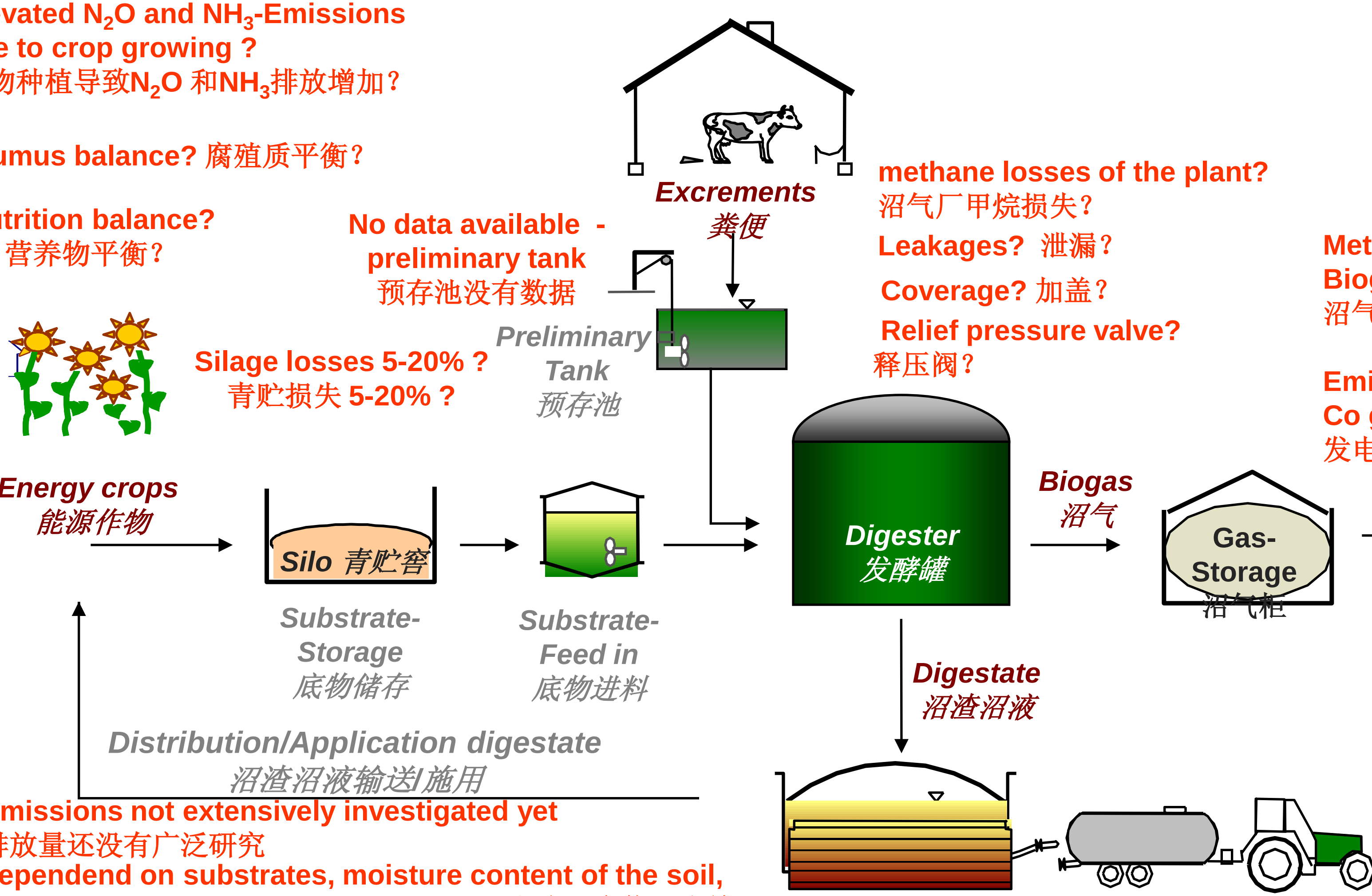
5. ASSESSMENT AND MONITORING OF LOSSES DURING THE FERMENTATION PROCESS发酵工艺中能量损失的评价和监测

Losses / Emissions 损失/排放

- Losses reduce the energy output and lead to emissions (gaseous, liquid, solid) 损失减少了能量产出并导致排放气体、液体和固体

- Need to minimize losses to 需要最小化损失，以
  - prevent environmental pollution 防止环境污染
  - avoid the release of greenhouse gases 避免释放温室气体
  - prevent the release of toxic substances 避免释放有毒物质
  - ensure high energy efficiency 确保高能效
  - ensure economical operation 确保运行的经济效益

Sources of emissions within the process chain
工艺流程中的排放源



Elevated N_2O and NH_3-Emissions due to crop growing ?
作物种植导致N_2O 和NH_3排放增加？

Humus balance? 腐殖质平衡？

Nutrition balance?
营养物平衡？

No data available - preliminary tank
预存池没有数据

Silage losses 5-20% ?
青贮损失 5-20% ?

methane losses of the plant?
沼气厂甲烷损失？

Leakages? 泄漏？

Coverage? 加盖？

Relief pressure valve?
释压阀？

Methane losses – Biogas upgrading?
沼气提纯甲烷损失

Emissions- from the Co generation unit ?
发电机排放？

Emissions not extensively investigated yet
排放量还没有广泛研究
dependend on substrates, moisture content of the soil, climate, time and period of application 取决于底物，土壤含水率，气候，施用时间和时长
Large variations in N_2O emissions N_2O 排放波动很大
Emissions influenced by distribution techniques 排放量受输送/使用技术 影响

e.g. Methane emissions from open storage tanks;
Dependend on processing + substrates 如开放储存池的甲烷排放，取决于工艺和底物

Possible losses I 可能的损失 I

- Silage storage facilities 青贮储存设施
  - ➢ *Respiration and decomposition of organic matter 有机物的呼吸和降解作用*
- Hopper/ preliminary tank/ open hydolysis 料斗/预存池/开放式水解池
  - Hopper used for mixing of substrate with digestate 用于混合底物和沼渣沼液的料斗
    - ➢ *Methane 甲烷(CH_4), Hydrogen氢气(H_2)*
  - Solid material feed in device 固体物料的进料装置
    - ➢ *Respiration and decomposition of organic matter有机物的呼吸和降解作用*
- Digester 发酵罐
  - Permeability of rubber membrane, leakages and pressure relief valves 橡胶模的渗透、泄漏以及释压阀
    - ➢ *Mainly Methane (CH_4) 主要是甲烷*

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Possible losses II可能的损失 II

- Storage tank (digestate) 储存罐（沼渣沼液）
    - *Methane (CH_4), nutrients (fertilizer value) (NH_3,(N_2O)) 甲烷(CH_4)，营养物（肥效）(NH_3,(N_2O))*

- Gas utilization 沼气利用
    - Co generation unit 发电机
        - *Mainly Methane (CH_4) and unburnt hydrocarbon (C_nH_m) 主要是甲烷(CH_4)和未燃尽的碳氢化合物(C_nH_m)*
    - Upgrading facilities (Feed in with natural gas quality) 提纯装置（达到天然气品质）
        - *Methane slip (CH_4) 甲烷损失(CH_4)*

5. Assessment and monitoring of losses during the fermentation process – Conclusion
发酵工艺中能量损失的评价和监测 – 结论

- due to environmental and economic reasons losses should be avoided 出于环境和经济原因，应避免损失
- Plant design, substrate and operation of the plant affect the amount of losses 沼气厂设计、底物和运行影响损失量
- Frequent check of the plant and operational management should be self-evident 需要经常检查沼气厂及其运行管理是不言而喻
- Actual – theoretical comparison is needed for precise identification of losses! 需要进行实际和理论计算结果的比较以准确确定损失

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6. POSSIBILITIES FOR SYSTEM OPTIMIZATION / INCREASE OF BIOGAS PLANTS PERFORMANCE (REPOWERING) 系统优化的可能性/增加沼气厂绩效的可能性

Evaluation for Optimization 优化评估

Aim: Achieving of a defined target state (optimum) by well-directed modification of current situation

目标：通过指导现状的修改达到既定的目标状态（最佳效果）

- Procedure 程序
- Process control 过程监测

- Availability 可用性
- Capacity utilization 容积利用率
- Efficiency 效率

- Greenhouse gas emissions 温室气体排放
- Odour emissions 臭气排放
- Noise emissions 噪音排放

- Investment costs 投资成本
- Operational costs 运行成本
- Income 收入

No independent optimization of isolated items possible, due to mutual dependency 出于相互的依赖性，不可能独立优化某一项

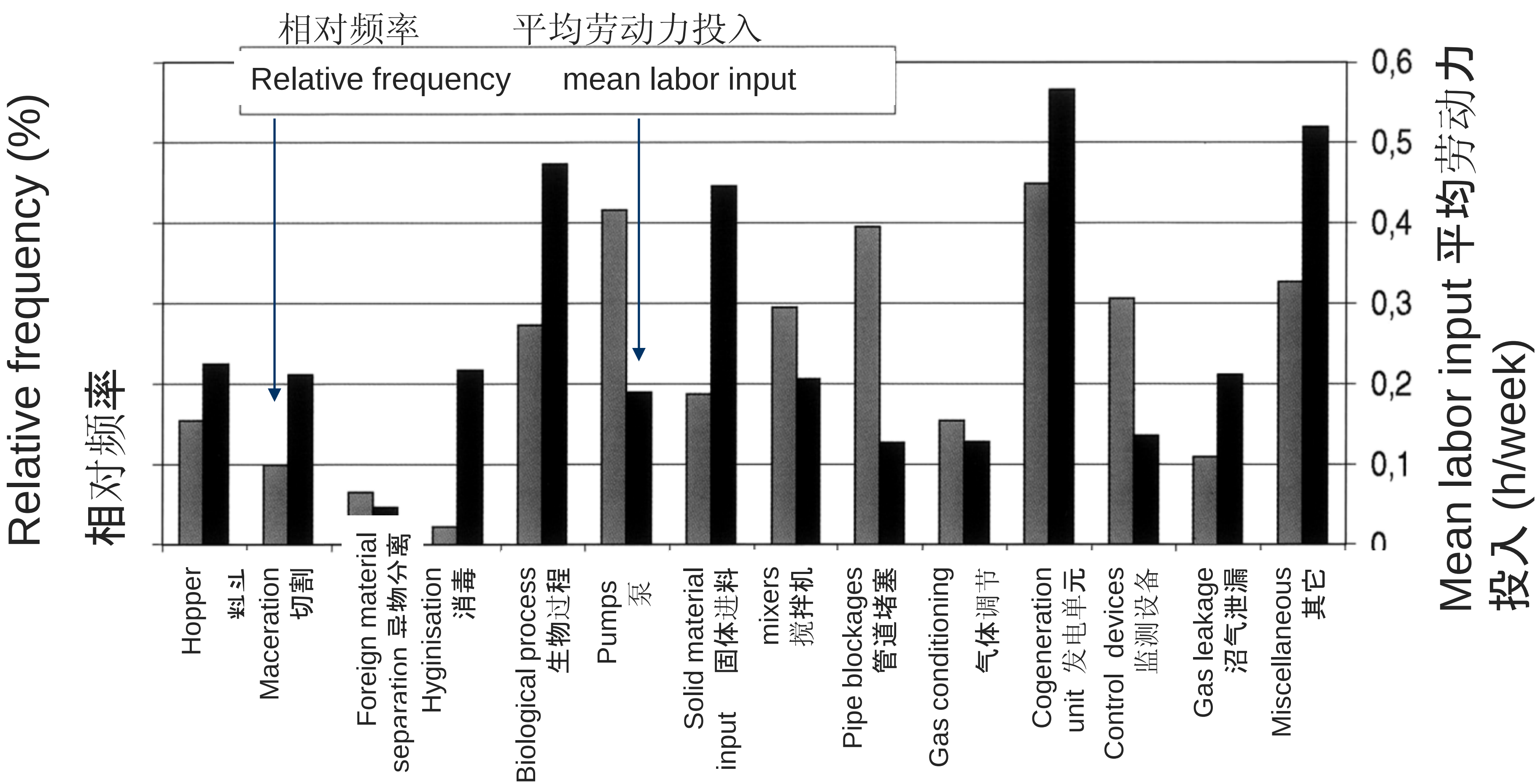
Source: Leitfaden Biogas; www.fnr.de

System Optimization 系统优化

Requirements: 要求

- Knowledge of the present situation needed - often gaps due to missing data, measurements or insufficient process monitoring
  需要了解现状-通常会因为数据、测量的缺失或过程监测的不足而导致出现知识空缺
- Operating conditions have to be kept as constant as possible, only then meaningful definition of the current status possible
  尽可能保持运行状态，只有这样才能有意义的定义现状

Causes of malfunction 导致故障的原因



Source: KTBL

System Optimization 系统优化

Fields of optimization: 优化环节

- **Technical procedure:** Availability, down time, smooth production flow

  → *Redundancy, spare parts, process measuring, maintenance intervals*

  技术程序：可用性、停工期、正常生产期

  → *冗余、备件、过程测量、维修间隔*

	Feeding tech. 进料设备	Mixing tech. 搅拌设备	Foam 泡沫	Floating layer 浮渣层	Acidity 酸度	Corrosion 腐蚀	CHP-unit热电联产
Number of feedback 反馈数量	263	186	24	52	46	26	410
Share of Feedback [%] (n=561) 反馈比例	46,9	33,2	4,3	9,3	8,2	4,6	73,1

Reference: DBFZ operator survey 2010

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System Optimization 系统优化

Fields of optimization: 优化环节

Mean operating hours, full load hours, standard deviation and median

平均运行时间、满负荷时间、标准差和中位数

	Mean 平均 (h/yr)	Standard deviation 标准差	Median 中位数	Number of operator´s feedback 操作员的反馈数
Operating hours 运行时间	8225	947	8500	510
Full load hours 满负荷时间	7673	1369	8000	359

Reference: DBFZ operator survey 2010

System Optimization 系统优化

Fields of optimization : 优化环节

- **Efficiency of overall plant** (improvement of energy balance, improvement of degradation rate, Minization of losses)

  →*Process control, leakages, substrate quality, share of heat usage, adaption of runtime of agitators / pumps*

  沼气厂整体的效率（能源平衡的改进、降解速率、损失最小化）

  →*过程监测、泄漏、质量不合格、热使用的共享、搅拌器/泵的运行时间调整*

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System Optimization 系统优化

Enhanced Efficiency
效率的提高

	Substrate intake 进料	Degradation/ biological process 降解/生态过程	Gas production 沼气生产
1	**Increased 增长的**	constant at increased digester volume 在发酵量增加的基础上保持	Increased 增长的
2	**Increased增长的**	accelerated at constant digester volume 在保持的发酵量上加速	Increased 增长的
3	Decreased 降低的	**improved** at constant digester volume 在不变的发酵量上改进	Constant 保持的
4	Constant 保持的	**improved** at constant digester volume 在不变的发酵量上改进	Increased 增长的

Optimization of Gas Usage 优化气体使用

- **Inefficient gas usage 气体的低效率使用**
  - main reason: insufficient usage of heat (CHP)
    主要原因： 热电联产使用的不够
- **Optimization: 优化**
  - Delivery of heat to heat sink/user (heating grid)
    将热传到热储罐/热网
  - Delivery of biogas to external CHP (demand of heat and electricity)
    将沼气传导外部的热电联产（需要热和电）
  - Upgrading of biogas to biomethane → feed in to the gas grid
    将沼气提纯到生物甲烷→进到燃气管网

System Optimization 系统优化

Fields of optimization : 优化环节

- **Economical optimization** - Reduction of expenditure, increase the revenue

  → *Revenues due energy and digestate (nutrition value); expenditure investion, substrate, opteration, Maintenance, Repair*

  经济优化-减少开支，增加收入

→*能源和沼渣沼液（营养成分）收入；费用投资、底物、运行、维护、维修*

- **Minimization of environmental impact** – containment of emissions of solid, liquid and gaseous substances

  → *Capture of process water with high organic load, engine adjustments (CHP), coverage of substrates and digestates, noise protection*

  最小化环境影响 - 控制固体、液体和气体的排放

  →*利用富含高有机成分的过程水、引擎调整、底物和沼渣沼液的遮盖、噪音防治*

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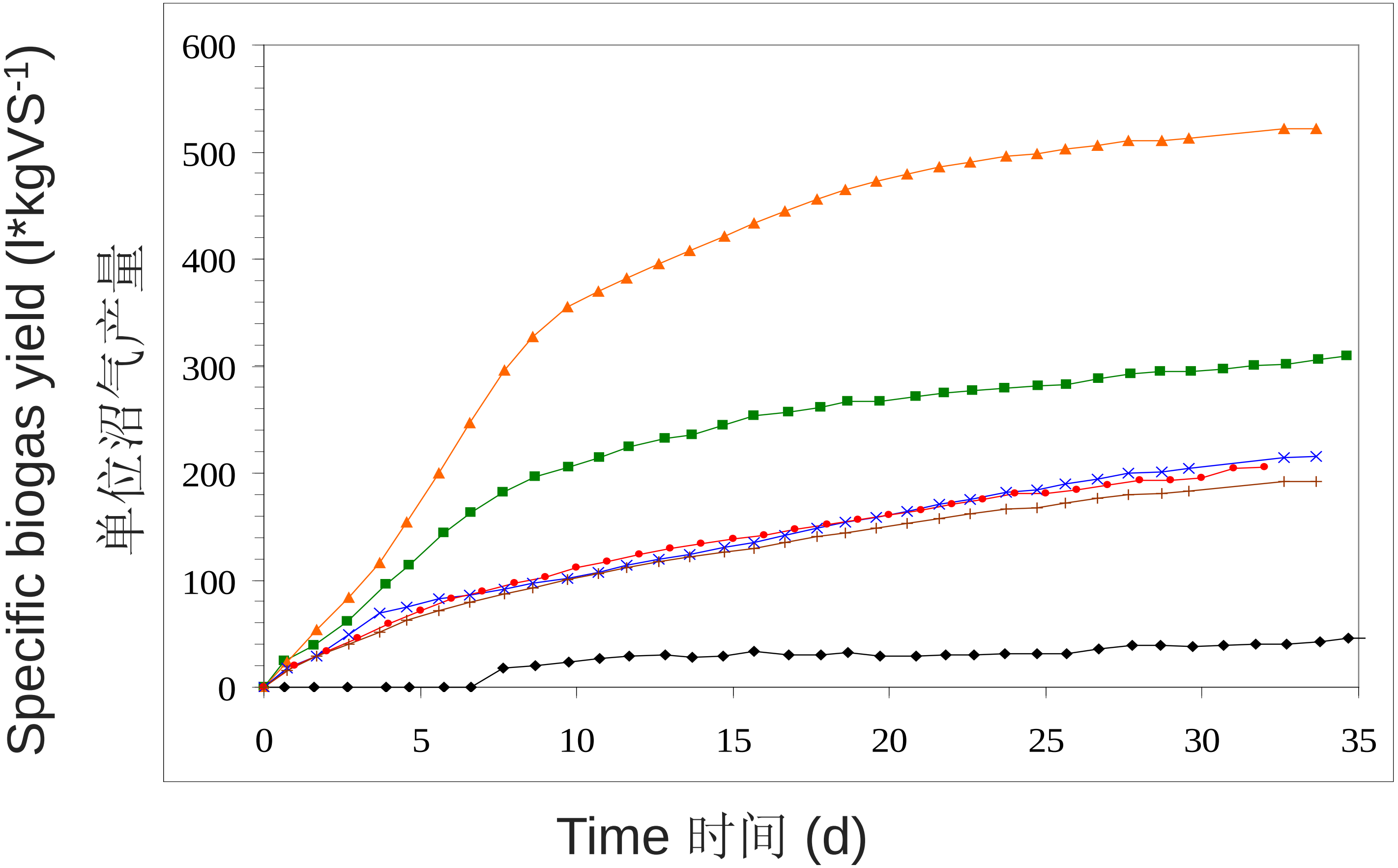
Gas potential of digestates
沼渣沼液的产沼潜力



Low retention times lead to incomplete substrate utilization 停留时间过短导致底物利用不充分

For comparison: 18-70 m³/t digestate 作为参考： 18-70 m³/t 沼渣沼液

6. Possibilities for system optimization - Conclusion系统优化的可能性 – 结论

- At first sufficient process data are essential 首先最重要的有足够的工艺数据。
- A biological stable state has to be the basis for any change consideration 任何改动考虑到基础是保证稳定的生物状态
- A comparison of data from literature or other plants should be drawn 应该和文献及其他沼气厂数据进行比较
- Target setting, but technical, environmental and economic optimization are mutual depend 设定目标，但技术、环境和经济方面的优化是互相关联的
- Frequent target-performance-comparison and new adaptions (iterative process) 经常比较目标和实际性能并采取新的措施（反复循环的过程）

Thank you very much for your attention!
谢谢！

Research for the Energy of the Future

研究未来能源

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